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EVALUATION OF NEW SELF-RECORDING AIR BLAST INSTRUMENTATION: PROJECT 1.3b OPERATION SNOWBALL

by

Daniel P. LeFevre

January 1967

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U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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EVALUATION OF NEW SELF-RECORDING AIR BLAST INSTRUMENTATION: PROJECT 1.3b OPERATION SNOW BALL

Daniel P. LeFevre

Terminal Ballistics Laboratory

This work was supported by
Defense Atomic Support Agency.

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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Aberdeen Proving Ground, Md.
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ABSTRACT

This report presents a description and evaluation of experimental self-recording pressure-time gages and triaxial accelerometers tested during Operation Snowball, an air blast experiment conducted at Suffield Experimental Station, Alberta, Canada. Values of shock overpressure, duration of positive phase of the shock wave, and impulse derived from the records of these gages are compared to graphs of similar parameters plotted from measurements obtained by Project 1.1 which was responsible for making primary measurements of the air blast parameters.

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1. INTRODUCTION

Operation Snowball, an air blast experiment in which a 500-ton hemispherical charge of TNT was exploded, was conducted at a test site at the Suffield Experimental Station (SES), Alberta, Canada. During this test, the Ballistic Research Laboratories (BRL) was responsible for Project 1.3b and other projects sponsored by the Defense Atomic Support Agency. To attain the objectives of Project 1.3b, the BRL personnel established a blast line and field tested a number of self-recording pressure-time gages and accelerometers developed under the BRL instrumentation development program. The performance of these various gages was evaluated by comparing the results provided by these gages with the results given by standard BRL gages located on an adjacent blast line.

1.1 Objectives

Project 1.3b had two objectives:

- To field test prototype instruments and compare the results with results from standard air-blast gages on the Project 1.1 blast line.
- To test and evaluate new components and techniques in self-contained instruments.

1.2 Background

The design, test, and evaluation of self-recording gages have been continuing efforts at the BRL since 1953. The BRL is a pioneer in the field of mechanical air-blast gage development. The first prototype developed under the current gage miniaturization program was field tested in 1962.

The first pressure sensors used by the BRL in these mechanical gages were capsules similar to those in general use on aneroid barometers. The capsule is constructed of two corrugated diaphragms welded together with the internal volume open to any given test pressure by means of a special aperture. A stylus and mounting base were adapted to the capsule, and a rotating recording medium was supplied for the stylus to scribe on. Sensors have progressed from the initial commercial model to an improved

specially manufactured capsule form, then to a single custom-made diaphragm, and finally to the present sensor. A detailed description of the sensor follows in Chapter 2.2.1.1.

The negator motor-recorder concept coupled with an electromechanical time base system was initiated in 1962. It has been tested on several field operations, and as a result improvements have been made on the gage. Snowball was the first full scale use of Negator gages.

Very briefly, the BRL mechanical gage development concentrates on rapid response pressure sensors, a dependable time base system, and a triaxial accelerometer, all with an accent on miniaturization. Some of the work is directed toward other program requirements and is under a research and development contract.

2. PROCEDURE

2.1 Operations

Test gages were placed in stations along a blast line which coincided with a blast line established by Project 1.1. This was advantageous because the responsibility of Project 1.1 was to make primary air blast measurements using standard BRL mechanical and electronic gages. This means of comparing data from the Project 1.3b experimental gages with the primary data from Project 1.1 provided a convenient measure of the performance of the new gages. The location of gage stations, the predicted overpressure, and identification of the various gages used, are shown in Figure 1. Pressure levels extended from 400 psi at the closest station to 0.01 psi at about 28 miles. Table I presents a summary of instrumentation.

The gages were initiated via signals originating from centrally located relay junctions at 570 feet and 1,000 feet. The signal cable to each gage was buried in a shallow trench. Timing signals were supplied via hard wire to the relay junctions by the SES sequence timer. Gages beyond 5,000 feet were initiated manually. Figures 2 and 3 show two typical gages being installed on the blast line.

G Z

STATION		RANGE	PSI
5	NAM	175'	400
6	M	205'	300
7	AM	250'	200
8	Z	305'	125
9	AZ	355'	90
10	T	410'	65
12	T	442'	55
18	S	630'	25
20	DP	800'	15
21	DSP	960'	10
22	P	1450'	5
24	V	10,160'	.5
25	V	19,550'	.1
26	V	149,000'	.01

SYMBOLS:

N - NEGATIVE SENSOR
A - PROTOTYPE ACCELEROMETER
M - PROTOTYPE PRESSURE
Z - ARRIVAL TIME
T - 100 CPS TIMER
S - NON-DIRECTIONAL
P - PHOTO CELL INITIATOR
V - VERY LOW PRESSURE
O - POROUS DISC DAMPING

FIGURE 1. PROJECT 1.3b BLAST LINE LAYOUT

TABLE I

INSTRUMENTATION LAYOUT

Station	Distance (Feet)	Predicted Pressure (psi)	Gage System
5	175	400	N - Negative Sensor, Disc
5	175	400	A - Test Accelerometer
5	175	400	M - Miniature Negator Prototype
6	205	300	M - Miniature Negator Prototype
7	250	200	A - Test Accelerometer
7	250	200	M - Miniature Negator Prototype
8	305	125	Z - Disc Arrival Time
9	355	90	A - Test Accelerometer
9	355	90	Z - Disc Arrival Time
10	410	65	T - Negator, 100 cps Oscillator
12	442	55	T - Negator, 100 cps Oscillator
18	630	25	S - Negator, Nondirectional
20	800	15	D - Negator, Porous Metal Orifice
21	960	10	S - Negator, Nondirectional
21	960	10	D - Negator, Porous Metal Orifice
24	10,160	.5	V - Negator, Very Low Pressure
25	19,550	.1	V - Negator, Very Low Pressure
26	149,000	.01	V - Negator, Very Low Pressure

FIGURE 2. MOUNTING A NEGATOR GAGE

FIGURE 3. MOUNTING A NONDIRECTIONAL SYSTEM

2.2 Instrumentation

2.2.1 Standard Pressure Instrumentation. Since we have referred to the BRL standard self-recording instrumentation, a brief description of these gages is presented below. The description follows in this order: the pressure sensing element, the negator gage, and the disc gages.

2.2.1.1 Sensors. The pressure sensors, Figure 4, are in various BRL self-recording pressure gages. The diaphragm 4c was used on all standard gages in the 10 psi to 40-psi region. The diaphragm and capsule units, 4a and 4b, were used in the low pressure ranges. The basic component of all units is a convoluted flexure disc of Ni Span C with attached stylus.

The newer sensors, 4c and 4d, are welded into mounting rings for ease of interchange from gage to gage. An osmium-tipped stylus and its spring arm are attached to the diaphragm by means of a section of stainless steel tubing. As the diaphragm flexes, the movement of the tubing is restrained to one axis by a sapphire jewelled bearing. The characteristics of these sensors are set out in Table II. These sensors are available in 15 ranges from 0.03 psi to 1,000 psi; four of the sensors are experimental. Natural frequency is approximately four times that of the older sensors and rated deflection is about half. Hysteresis is generally within 1 percent and linearity well within an acceptable 5 percent for mechanical instrumentation. A definition of (terminal based) linearity is the maximum deviation of the calibration curve from a straight line drawn through its origin and the point of 100 percent rated pressure.

2.2.1.2 Standard Negator Gage. Figure 5 shows the standard negator gage. The method of using a negator spring as both a drive motor and a recording medium was devised and patented by the BRL. The stainless steel spring provides a constant torque as it unwinds from a supply drum, travels around the recording drum, and into its designed configuration on a take-up drum. The excursions of three stylii are recorded; these

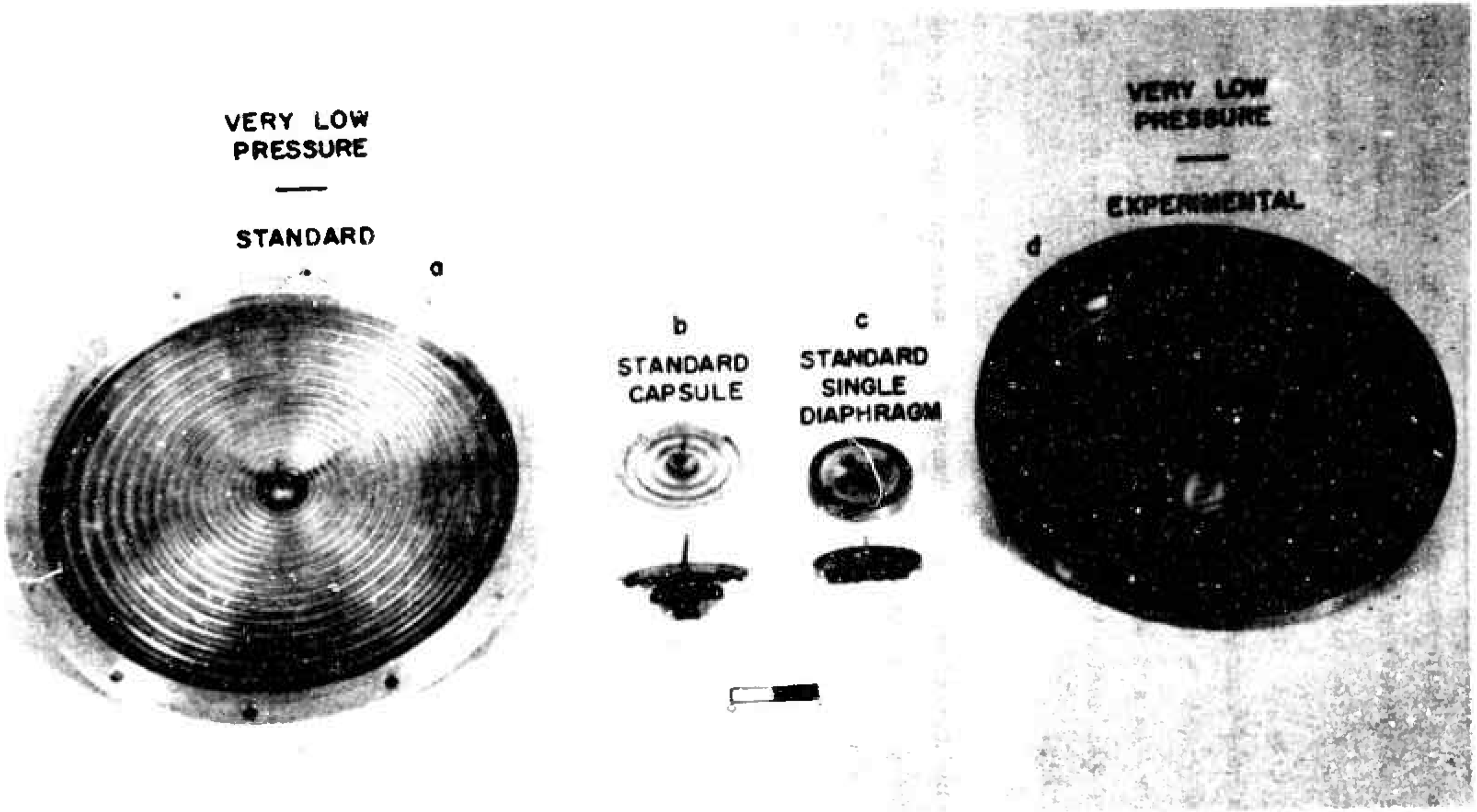

FIGURE 4. BRL PRESSURE SENSORS

TABLE II

SENSOR CHARACTERISTICS, TYPE 4c AND 4d

Sensor Range (psi)	Nat. Freq. (Undamped) (cps)	Deflection at Rated Pressure (mils)	Hysteresis (%)	Linearity (Terminal Based) %
0-1000	6990	20.10	0.59	0.45
0-600	5955	20.82	0.62	2.16
0-400	5105	23.17	0.86	3.75
0-200	4351	31.35	0.73	3.57
0-100	3615	28.60	0.35	0.87
0-50	2995	24.20	0.30	2.40
0-20	2726	23.90	0.20	0.70
0-10	1895	26.80	0.67	2.69
0-5	1570	20.20	0.00	1.60
0-2	1085	19.60	0.87	1.68
0-1	820	15.30	0.70	1.60
Experimental				
0-0.5	430	18.15	0.55	1.70
0-0.125	250	17.40	0.60	4.90
0-0.030	250	18.20	1.10	4.20
0-10 Negative	1915	25.70	0.20	0.70

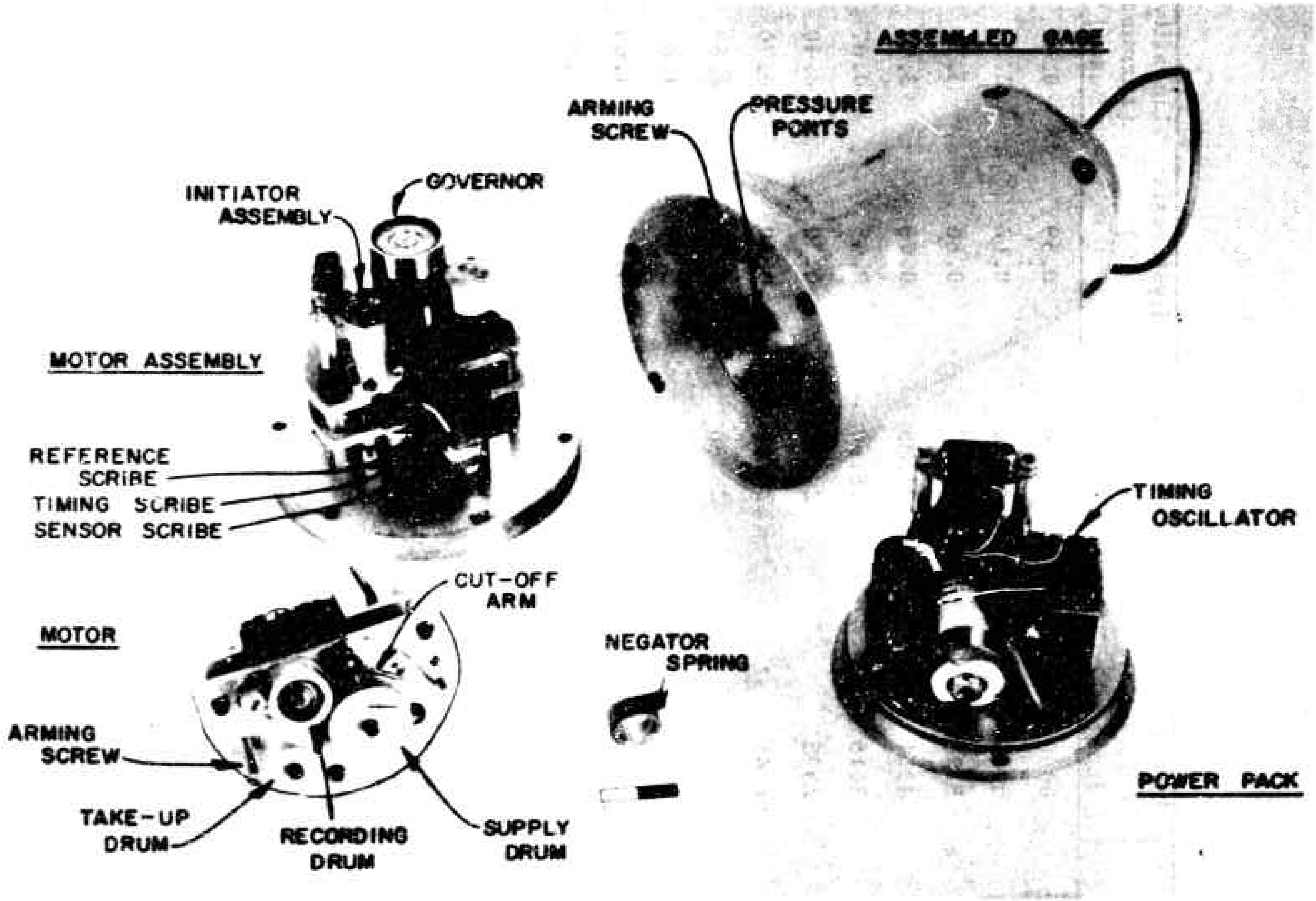

FIGURE 5. STANDARD NEGATOR PRESSURE GAGE

excursions represent pressure, time base, and reference. These are recorded on the spring's microhoned surface as it travels around the recording drum. A balanced friction governor geared to the supply drum provides a spring travel rate of about 3 inches per second. A square-wave time base trace is supplied by a solenoid driven scriber which receives a signal of 50 cycles per second from an electromechanical oscillator. A simple mechanism is provided for arming the gage and for cutting it off when the spring reaches the end of its travel. Two methods are used to initiate the gage; a solenoid on earlier models and a more rapid explosive piston actuator on newer models, both triggered by an externally supplied relay circuit closure. In each case the motor is given a spring-driven "kick" in order to decrease the time required to bring the spring travel rate up to constant speed. Figure 2 shows the mount used in pressure regions above 50 psi. At the lower pressure ranges, any BRL self-recording gage may be mounted simply in the ground.

2.2.1.3 Standard Disc Gage. Figure 6 shows the standard disc gage. The turntable is driven by a conventional governed DC motor and a microhoned stainless steel disc is used as the recording medium. A time trace is supplied by a system identical to that used on the negator gage. The disc gage is normally mounted the same as the negator gage. Figure 7 is a modification of the disc gage which is used for dynamic pressure measurements. A similar microhoned disc records both total and side-on pressure histories. The method of field mounting is shown at the top in the figure.

2.2.2 Experimental Gages

Experimental gages tested during Operation Snowball included a nondirectional side-on pressure gage, a negative pressure gage, a standard disc gage with a zero-time adapter, a modified standard negator pressure gage, a very low pressure gage, a miniature blast pressure gage, and a triaxial accelerometer. These gages are described briefly in the following sections.

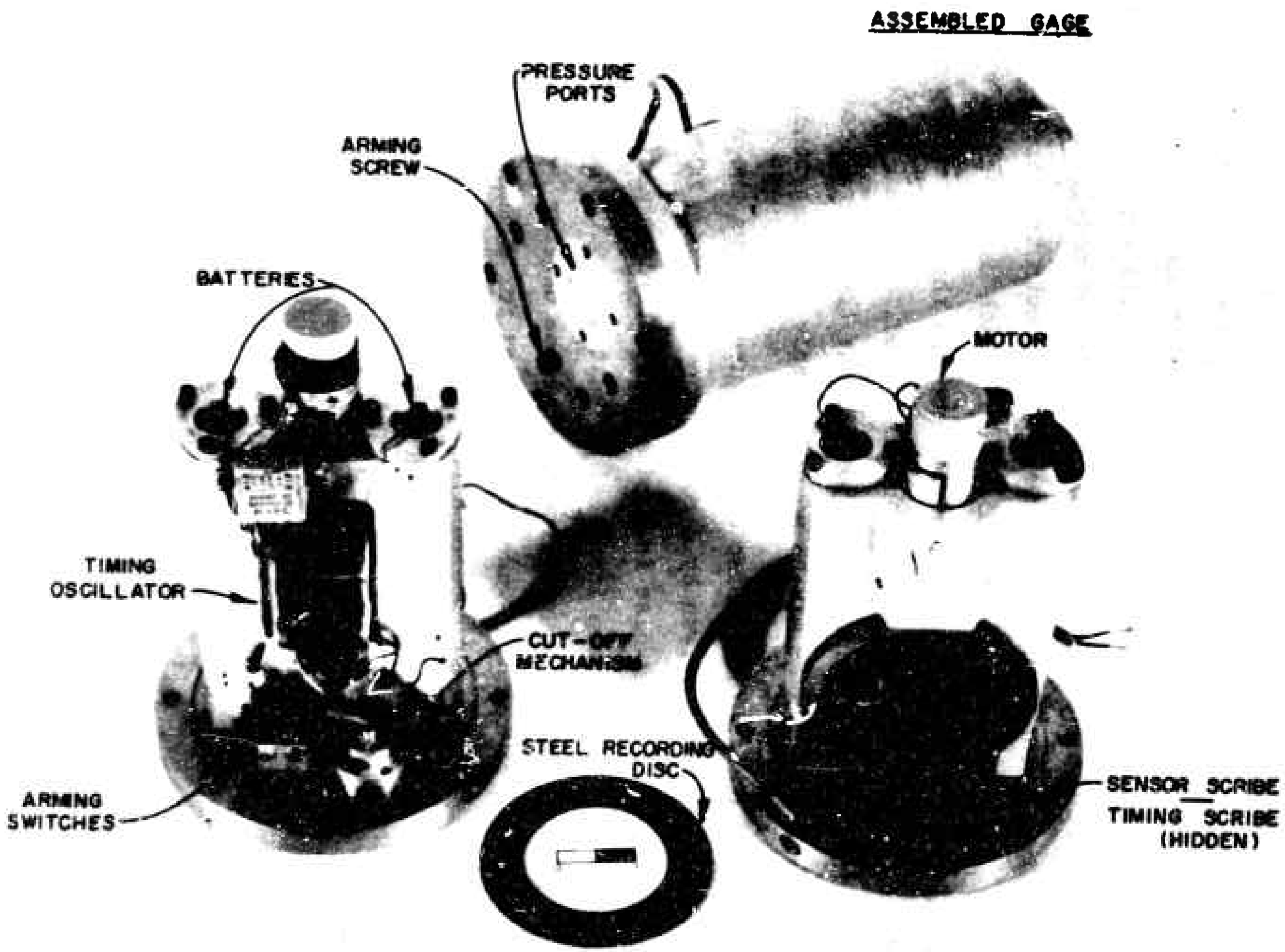

FIGURE 6. STANDARD DISC PRESSURE GAGE

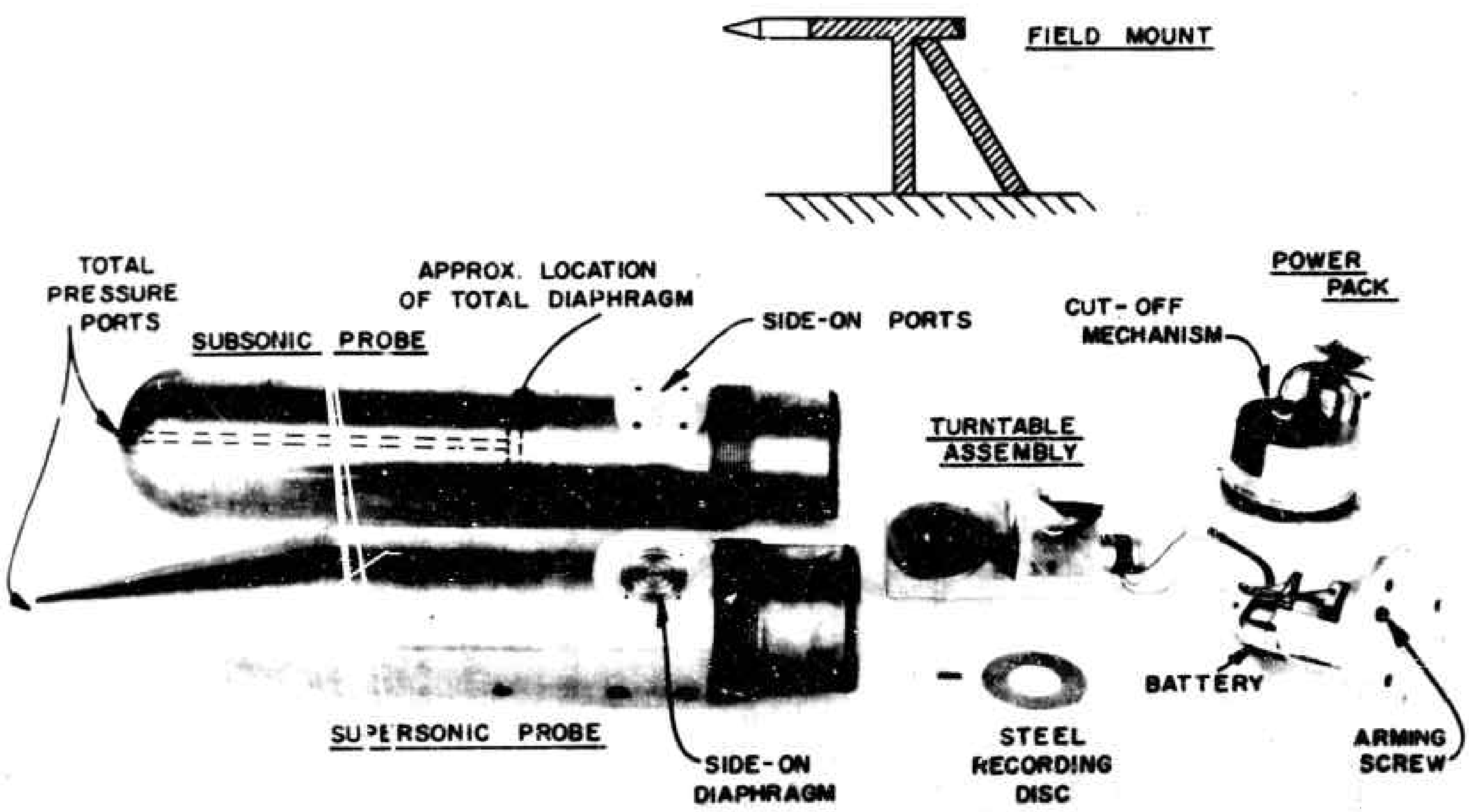

FIGURE 7. DYNAMIC PRESSURE GAGE

2.2.2.1 Nondirectional Gage System. The first experimental unit is a standard negator gage mounted within a perforated sphere. Figure 8 is a schematic of a nondirectional system which was designed to measure side-on overpressure where gage orientation is a problem, such as suspension from a balloon. The test mount consists of a suspended cable from which the gage hangs freely (see Figure 3). Nondirectional measurements were made at the 10 and 25-psi ranges.

2.2.2.2 Negative Pressure Gage. The second experimental unit was a negative pressure sensor designed to measure accurately the negative phase in a high pressure region. The sensor seen in Figure 4c was modified to restrict the positive deflection of a 10-psi diaphragm but allow full travel in the negative direction. One of these units was used at the 100-psi level. The recording medium used was a disc gage, and the field mount was similar to that shown in Figure 2.

2.2.2.3 Standard Disc Gage with an Arrival Time Indicator. An arrival time system, Figure 9, consists of a standard disc gage with a zero-time adapter for scribing a fiducial mark on the recording disc. The scribe is attached to an explosive piston actuator which is triggered by a simple photo cell device shown at left. This device was designed to record more accurately the arrival time. It was tested at the 90 and 125-psi ranges in a ground surface mount similar to that illustrated in Figure 2.

2.2.2.4 Modified Standard Gages. Two late models of the standard negator gage were tested in the 55 and 65-psi ranges. These gages are equipped with an explosive piston actuator in place of the solenoid initiator, and the 50-cycle-time oscillator was replaced with a 100-cycle generator. The higher rate time trace was the primary test item.

An experimental damping medium was tested on the standard negator gage at the 15 and 10-psi levels. The conventional aperture which separates the sensor diaphragm from the incident pressure

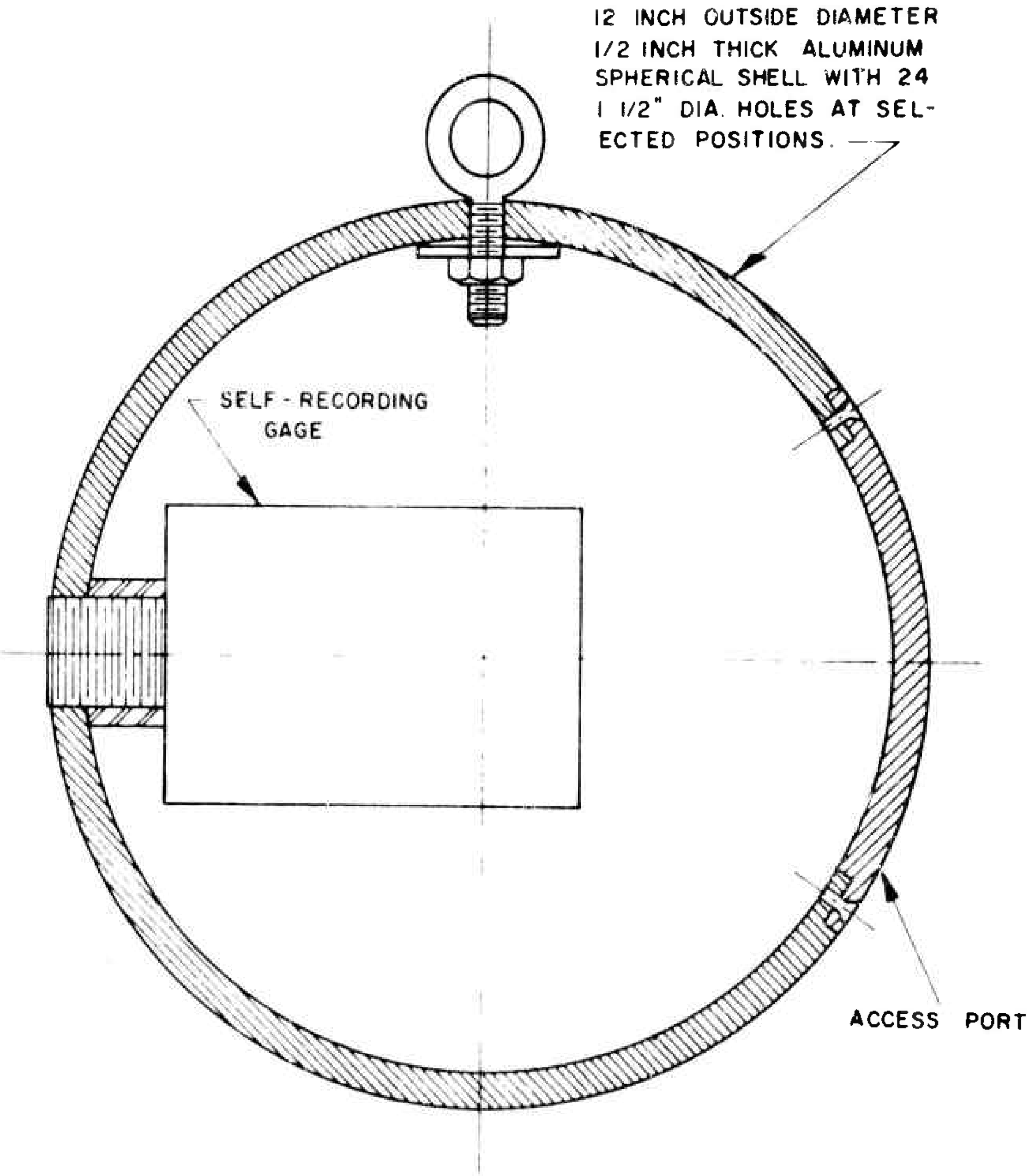

FIGURE 8. NONDIRECTIONAL SYSTEM

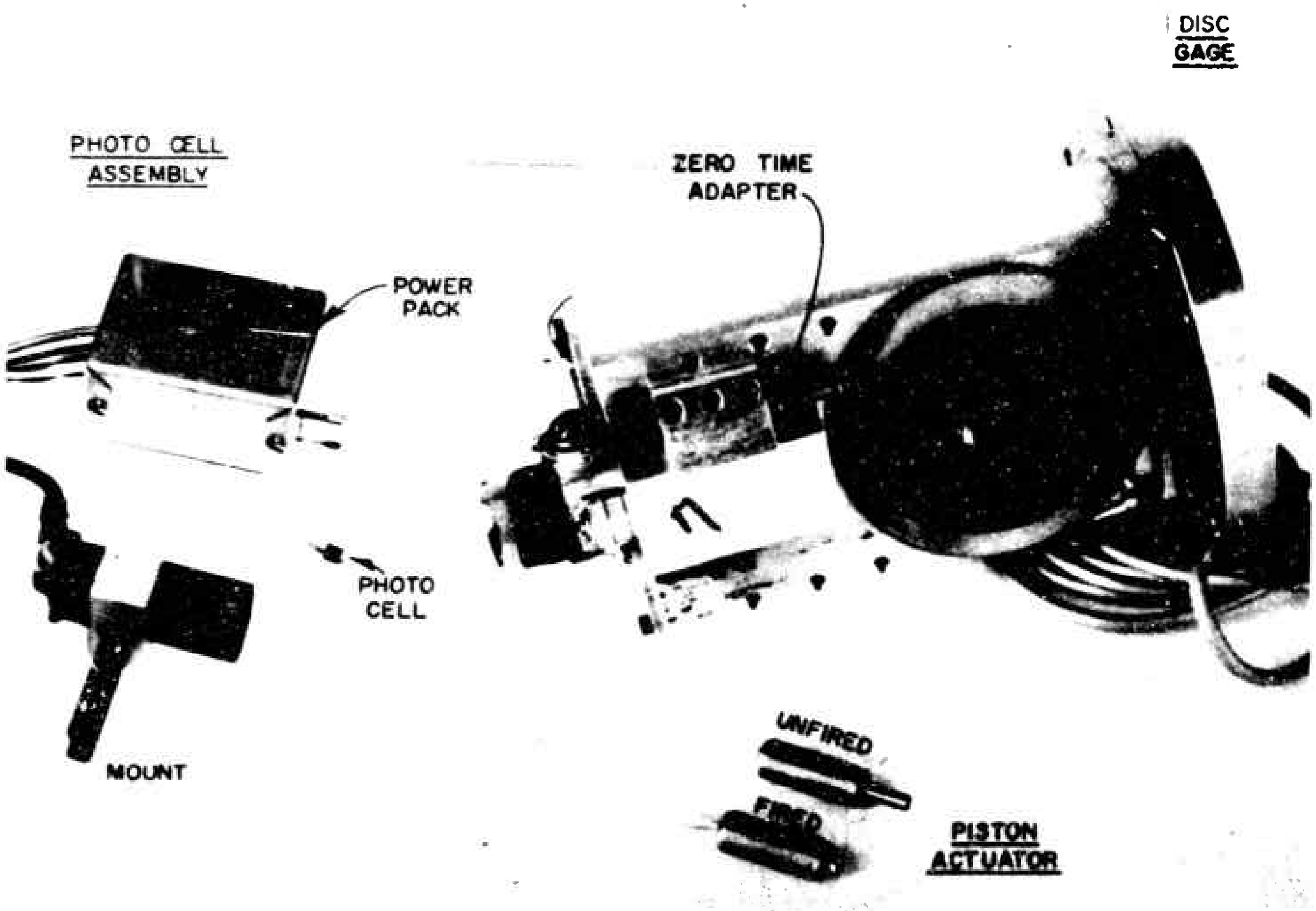

FIGURE 9. ARRIVAL TIME SYSTEM

was replaced with a porous metal damping disc. This damping material is made by compressing sintered stainless steel into a mass of varying density. Damping is measured in percent dense where 100 percent is solid metal.

The photo cell assembly (Figure 9) was designed for use as a zero-time initiator for the BRL mechanical gages. It was tested at five different ranges, including the two arrival time systems described above.

2.2.2.5 Very Low Pressure Gage. Figure 10 is the experimental low pressure (VLP) gage (first major design change). It has three interchangeable sensors, 0.5, 0.125, and 0.03 psi. The natural frequency has been increased by a factor of five with a corresponding decrease in response time. The combination of a stainless steel gage case and a pressure equalizing system has helped solve the problems associated with internal pressure changes in earlier models which were caused by changing temperature conditions outside the gage.

The gage is essentially a standard negator gage adapted for use with the very low pressure diaphragm as shown in Figure 4d. The addition of an explosive piston actuator both activates the gage and supplies a "kick" to the motor and governor, replacing the spring "kicker" used on the standard gage. This improvement has decreased the spring motor start-up time from 20 msec to about 5 msec. Three VLP gages were tested in the 0.5, 0.1, and 0.01 psi ranges. No prepared mounting facility is required.

2.2.2.6 Prototype Accelerometer and Pressure Gages. The BRL field tested six prototype gages: three miniature blast pressure gages and three triaxial accelerometers. All are the result of a research and development contract with Friez Instrument Division, Bendix Corporation.

The blast gage uses the pressure sensor shown in Figure 4c. There are three major departures from the standard negator gage: a 50-percent reduction in the physical size of the motor unit; an

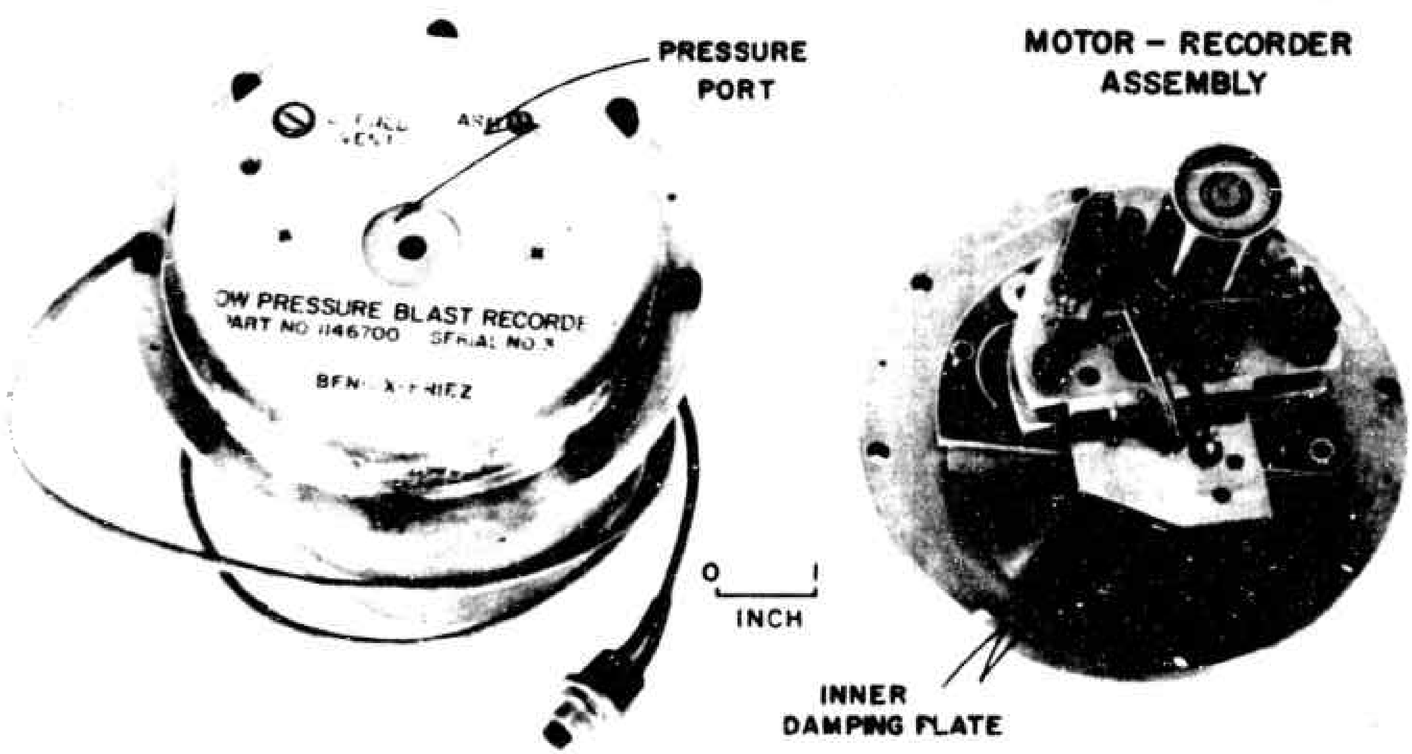

FIGURE 10. VERY LOW PRESSURE GAGE

increase in the time base frequency to 200 cycles; and an explosive piston actuator device identical to that on the VLP gage described in the preceding paragraph.

The accelerometer makes use of a liquid mass and coupling approach as sensing elements and an all-fluid oscillator as the time base generator. Both the blast gage and accelerometer use the standard mount shown in Figure 2.

A comprehensive discussion of the development and evaluation of the blast gage and triaxial accelerometer has been prepared by the contractor and is presented as an Appendix.

2.3 Calibration

Calibration of all gages and components was completed before project personnel departed for SES. Static calibration of the pressure sensors was performed at the BRL, and dynamic tests were made in the BRL shock tubes. A brief description of available shock tube facilities at the BRL is presented in the Snowball Project 1.1 report[1,2*]. Results of the dynamic tests are shown in Figures 11 and 12 which compare the values obtained by the self-recording (mechanical) gages with those obtained by electronic gages. Both the 24-inch air tube and the 8-inch gas tube were used in the calibration of the sensors.

Calibration of the six prototype gages was performed by the contractor prior to delivery at SES and is described in detail in the Appendix.

2.4 Data Processing

Records are reduced to tabulator form by electronic means. The records are first read with the aid of a toolmakers microscope equipped with magnetic read-out heads which feed information directly to IBM cards. The information is also presented in typed form. These IBM cards, together with cards representing time interval and calibration steps are fed into the BRL Electronic Scientific Computer (BRLESC). The pressure values are calculated from a straight-line interpolation between the

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* *Superscript numbers denote references which may be found on page 44.*

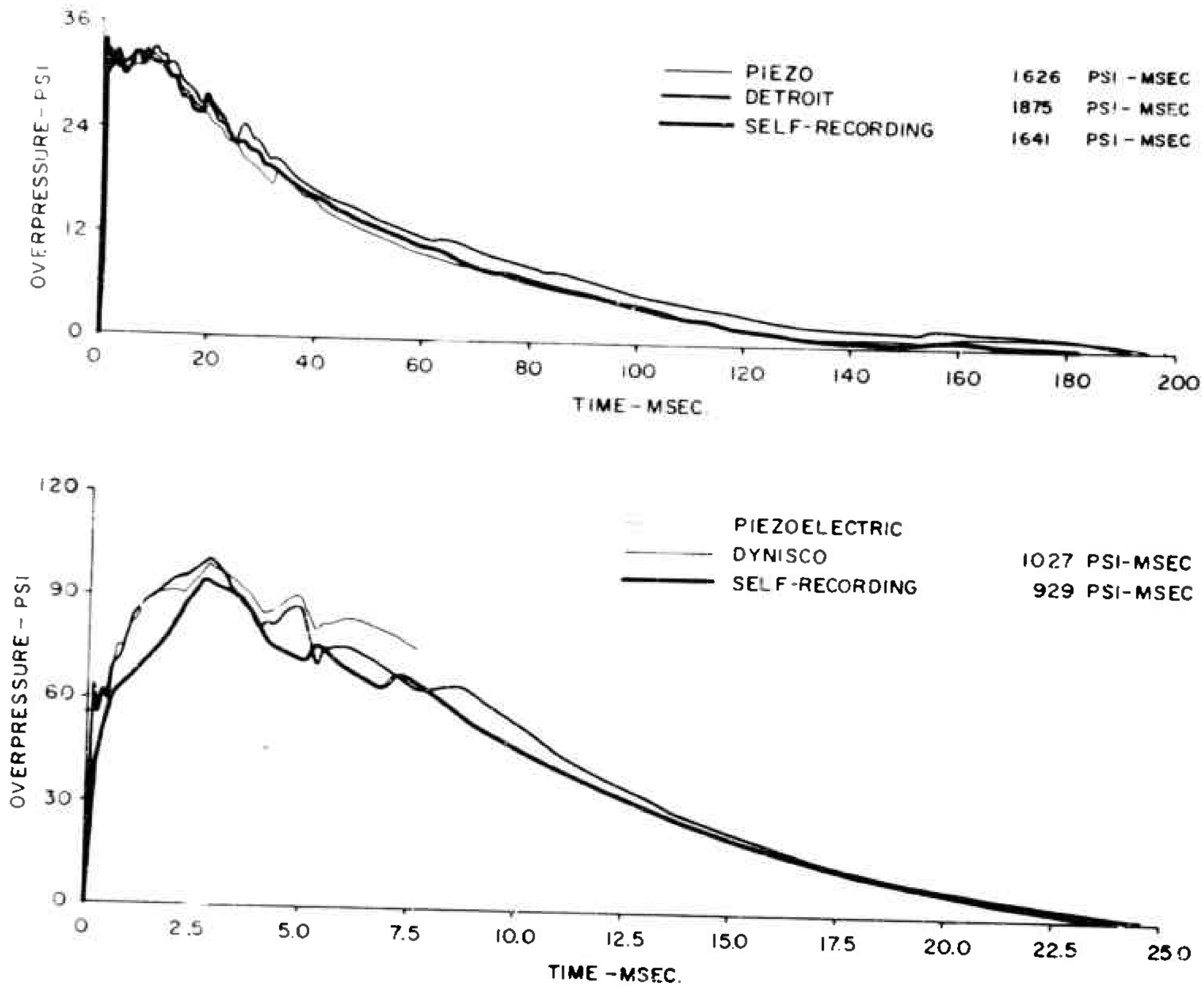

FIGURE 11. COMPARISON OF SHOCK TUBE TESTS OF SELF-RECORDING AND ELECTRONIC GAGES

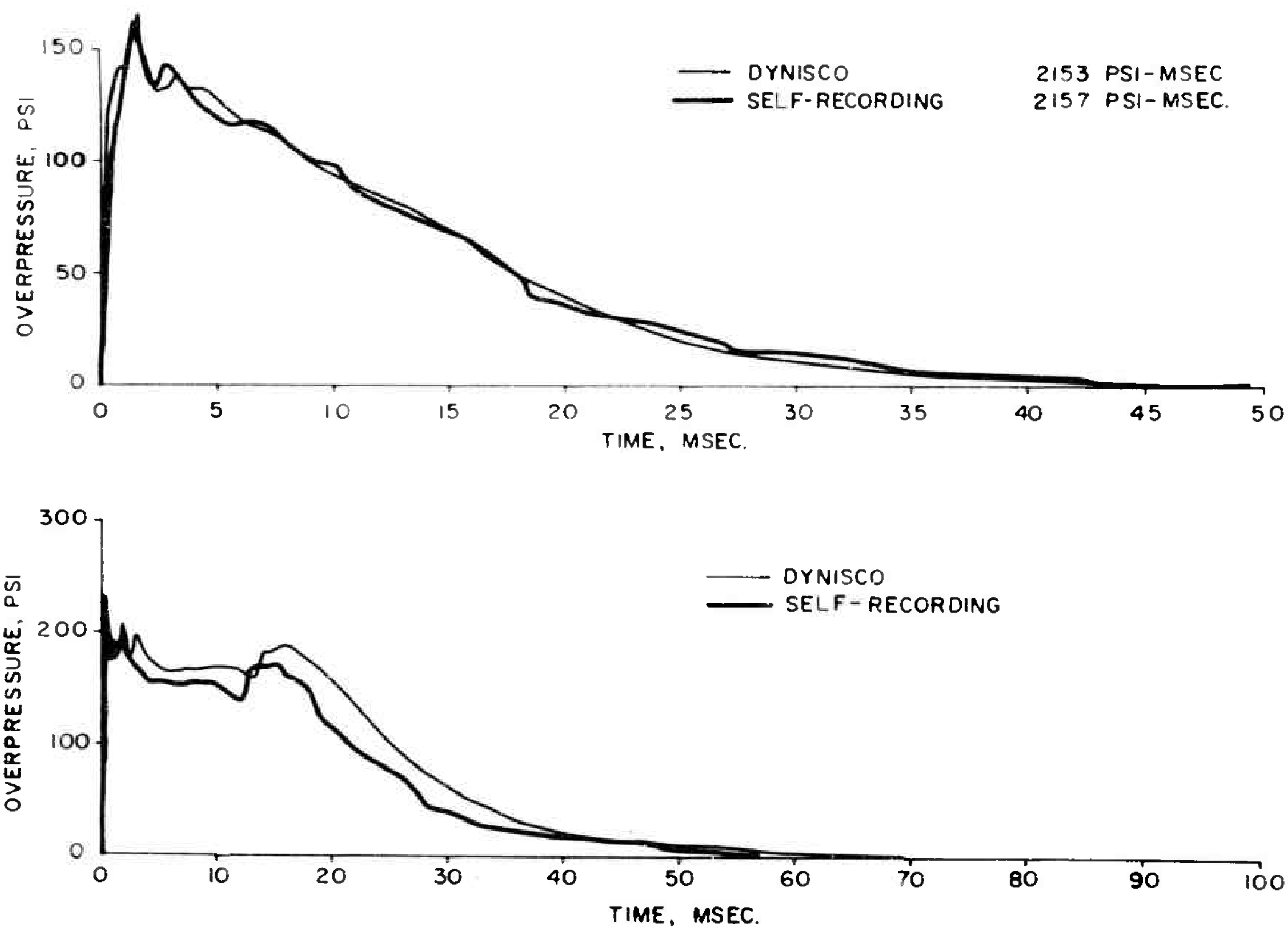

FIGURE 12. COMPARISON OF SHOCK TUBE TESTS OF SELF-RECORDING AND ELECTRONIC GAGES

various calibration steps. The output, in final form, is entered on IBM cards. Information on these cards is then used to prepare pressure-time plots and typed tabulations of pressure, time, and impulse (psi/msec).

3. RESULTS

3.1 Pressure Data

The performance of the experimental self-recording instrumentation and the resulting data are shown in Table III; with few exceptions valuable data were obtained. A comparison of the data with that obtained by Project 1.1 is shown in Figures 13 thru 15. Figures 16 thru 18 show graphs of pressure as a function of time which were derived from the information contained on the individual gage records.

3.2 Instrumentation Components and Systems

3.2.1 Nondirectional System. Both gages provided data that agreed well with 1.1 data. The gage at 650 feet was underdamped, and its time base scriber failed. Data from the gage located at 960 feet are shown compared with data from a 1.1 record in Figure 20.

3.2.2 Negative Sensor. The gage operated but the sensor failed when hit by the shock front. The time base scriber performed well.

3.2.3 Arrival Time Indicator. Data from the gages at both stations agree with that provided by 1.1 gages (see Figure 19). The zero-time adapter on the gage at 305 feet fired prematurely, and the time base scriber was sensitive to shock. As for the gage at the 355-foot station, the time trace oscillations were clearly resolved; the zero-time adapter left a clear trace, and the arrival time measured agreed well with predicted data.

3.2.4 Modified Standard Gages. Results from both gages that had the 100-cps timer agree with the 1.1 data. A comparison of the 442-foot gage with a standard gage is shown in Figure 20. Performance of the 100-cps time base system was not satisfactory. The two gages with porous disc

TABLE III

EXPERIMENTAL SELF-RECORDING INSTRUMENTATION

Sta. No.	Distance Ft.	Gage Type	Sensor No.	Maximum Over-Pressure psi	Positive Duration msec	Positive Over-Pressure Impulse psi msec	Remarks
5	175	M-Negator	62-6	425*	21	1855	Prototype gage, poor record
5	175	N-Disc	11-1	-	-	-	Negative pressure diaphragm, no record, sensor failed.
6	205	M-Negator	42-8	350	70	-	Prototype gage, questionable record
7	250	M-Negator	22-10	160	75	2000	Prototype gage, good record
8	305	Z-Disc	22-1	118	140	3030	Zero timer failed, fair record
9	355	Z-Disc	22-2	90	135	1960	Zero timer functioned, good record
10	410	T-Negator	12-5	63	108	2020	Questionable perturbation in decay, 45-70 msec poor time trace
12	442	T-Negator	12-7	53	98	1230	Gage overdamped, peak extrapolated, poor time trace
18	630	S-Negator	50-2	26	125	845	Nondirectional gage, under-damped
20	800	D-Negator	25-3	13.7	210	925	Porous plug damped, good record

* *Questionable value; not plotted on comparison curve (see text).*

TABLE III (Contd)

21	960	D-Negator	10-2	9.6	210	667	Porous plug damped, good record
21	960	S-Negator	10-6	9.2	240	787	Nondirectional gage, good record
24	10,160	V-Negator	48-2	.29	545	73.7	Very low pressure sensor, good record
25	19,550	V-Negator	18-2	.04	-	-	Peak only, motor failed
26	149,000	V-Negator	38-2	-	-	-	Gage functioned, pressure too low for sensor to record

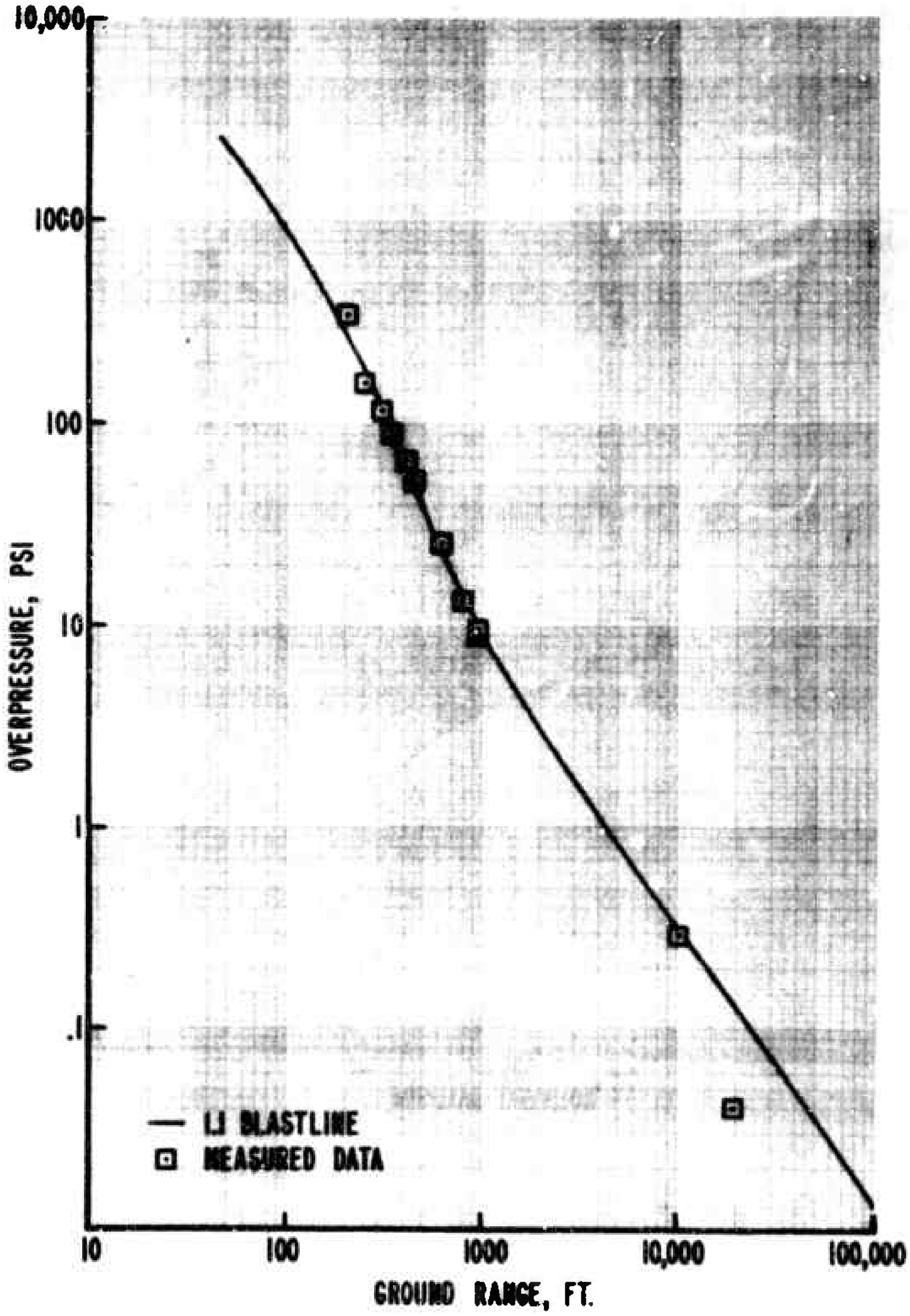

FIGURE 13. PROJECT 1.3b MEASURED MAXIMUM OVERPRESSURE VERSUS GROUND RANGE COMPARED WITH PROJECT 1.1 MEASURED DATA

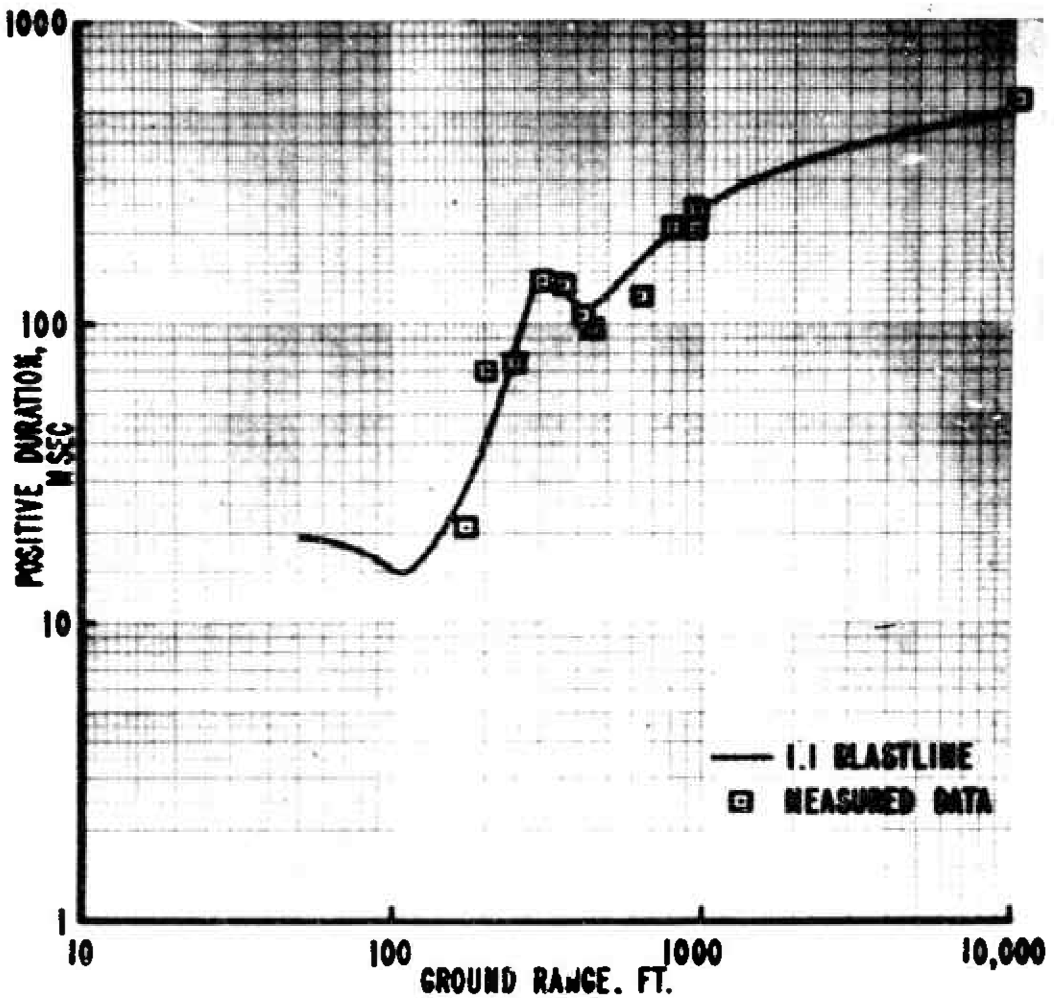

FIGURE 14. PROJECT 1.3b MEASURED POSITIVE DURATION VERSUS GROUND RANGE COMPARED WITH PROJECT 1.1 MEASURED DATA

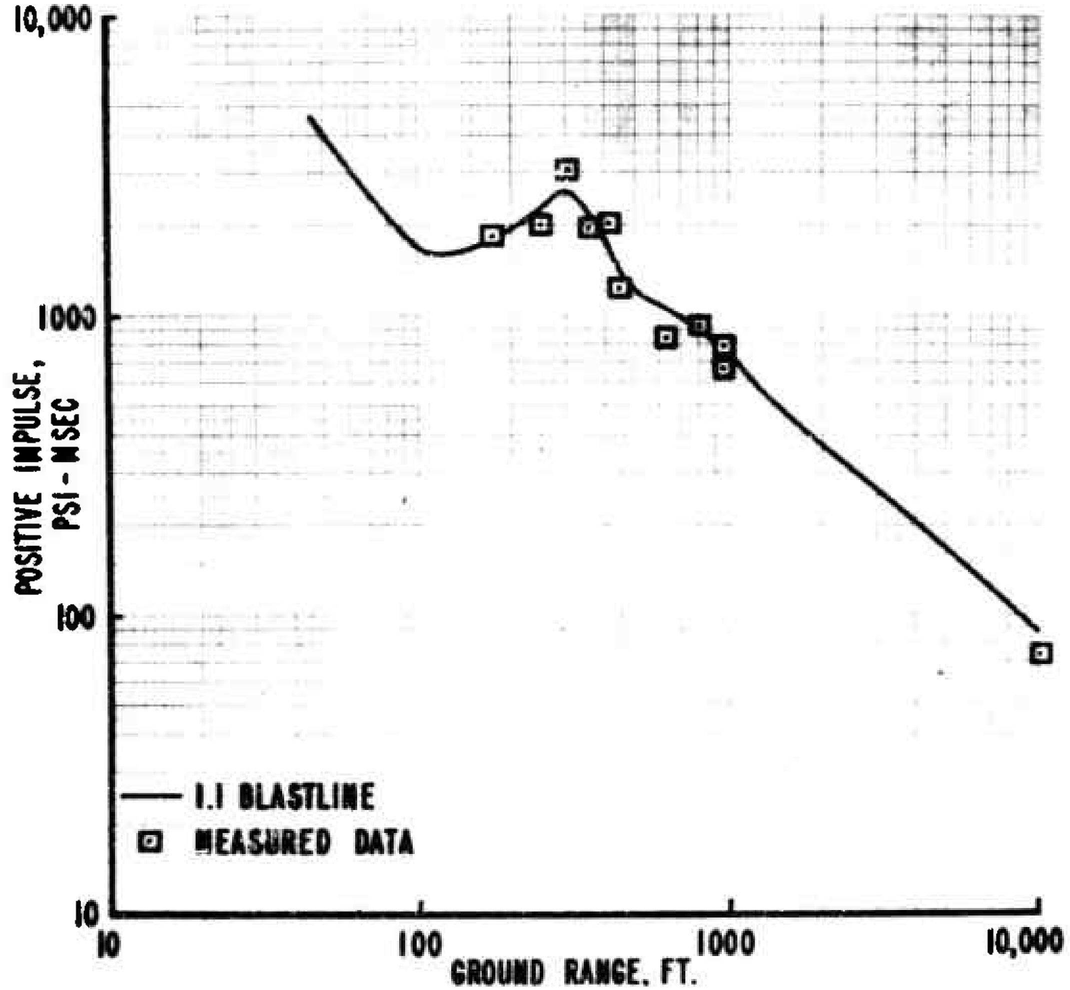

FIGURE 15. PROJECT 1.3b MEASURED POSITIVE IMPULSE VERSUS GROUND RANGE COMPARED WITH PROJECT 1.1 MEASURED DATA

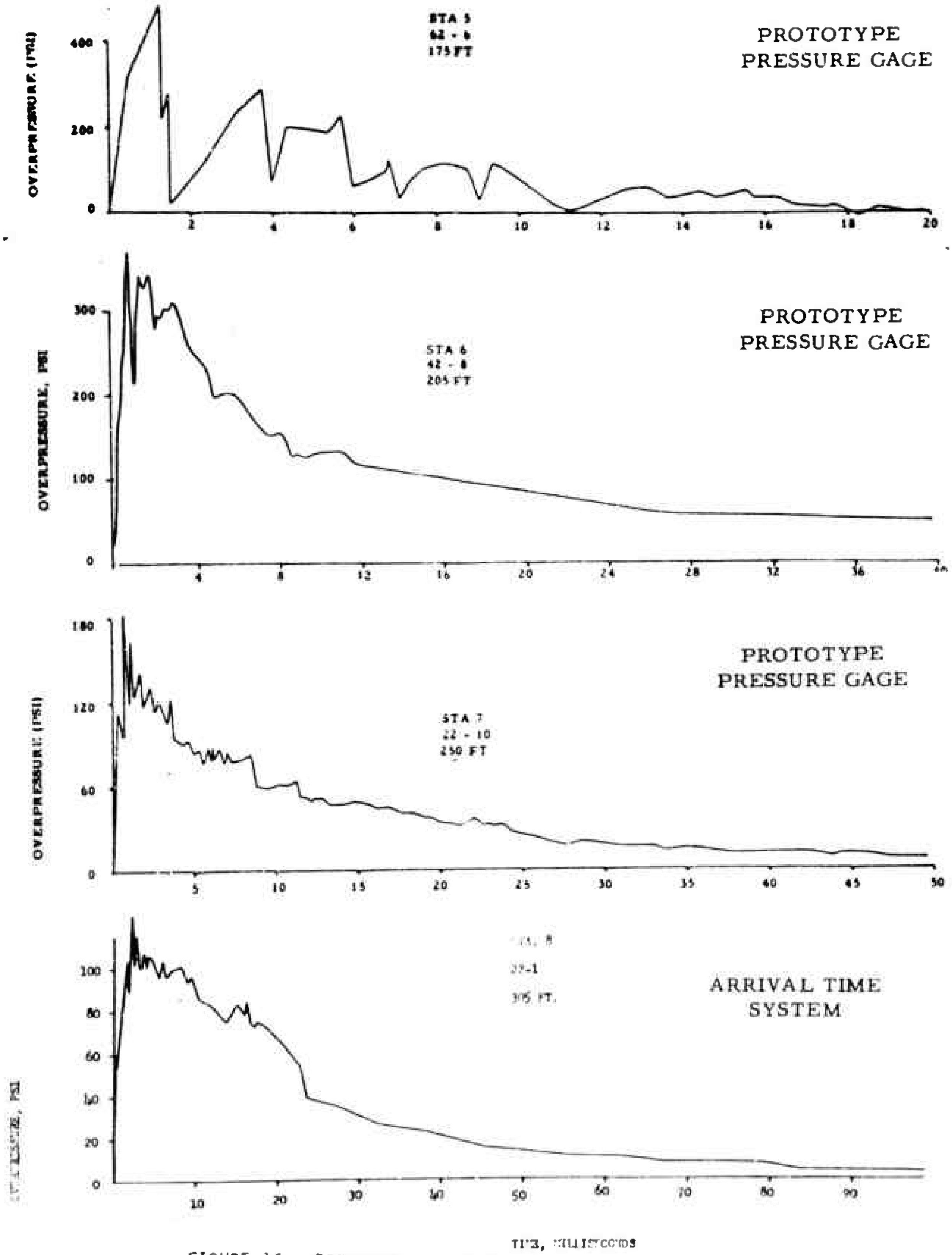

FIGURE 16. PRESSURE VERSUS TIME PLOTS HIGH PRESSURE REGION

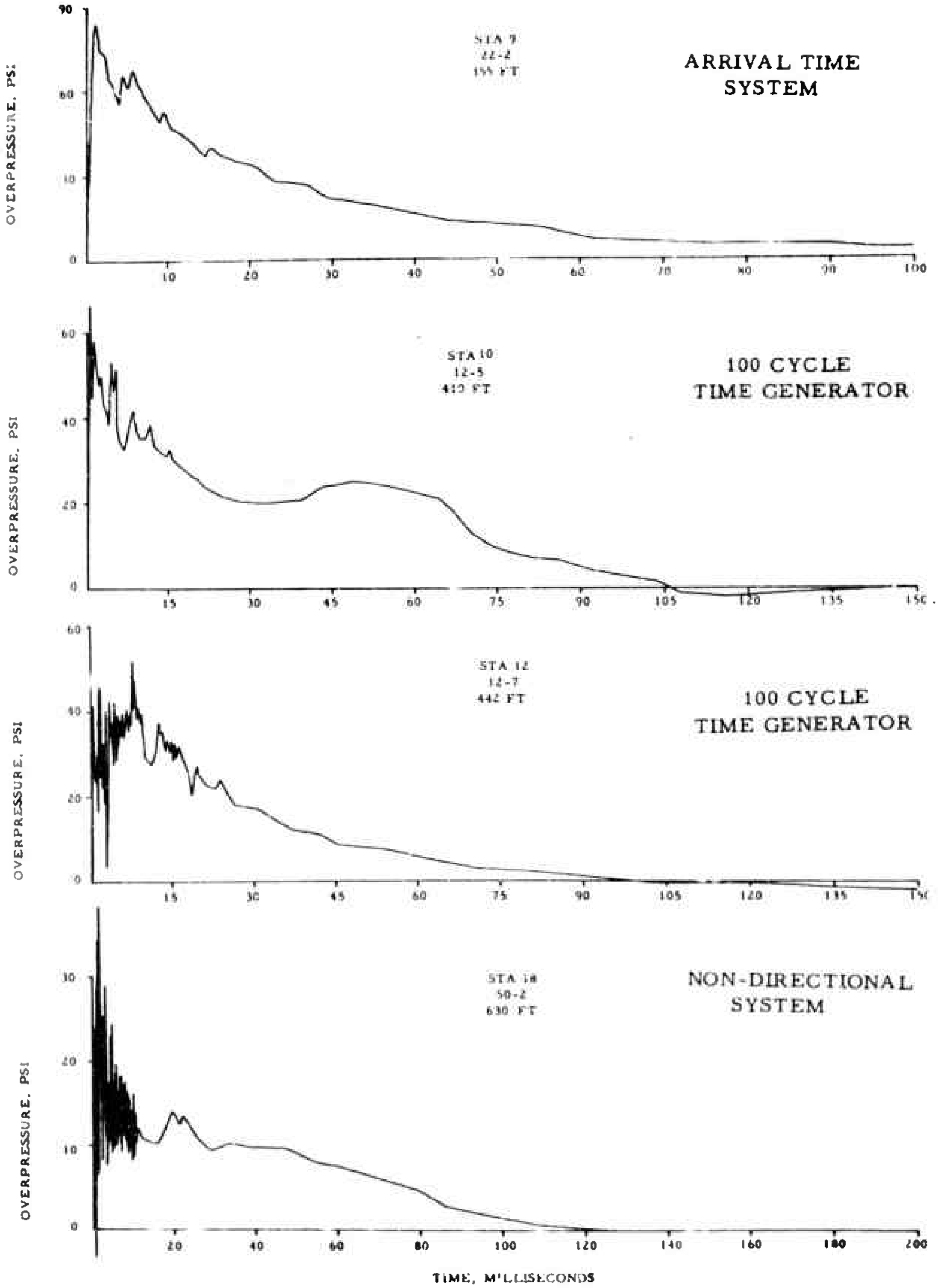

FIGURE 17. PRESSURE VERSUS TIME PLOTS, MEDIUM PRESSURE REGION

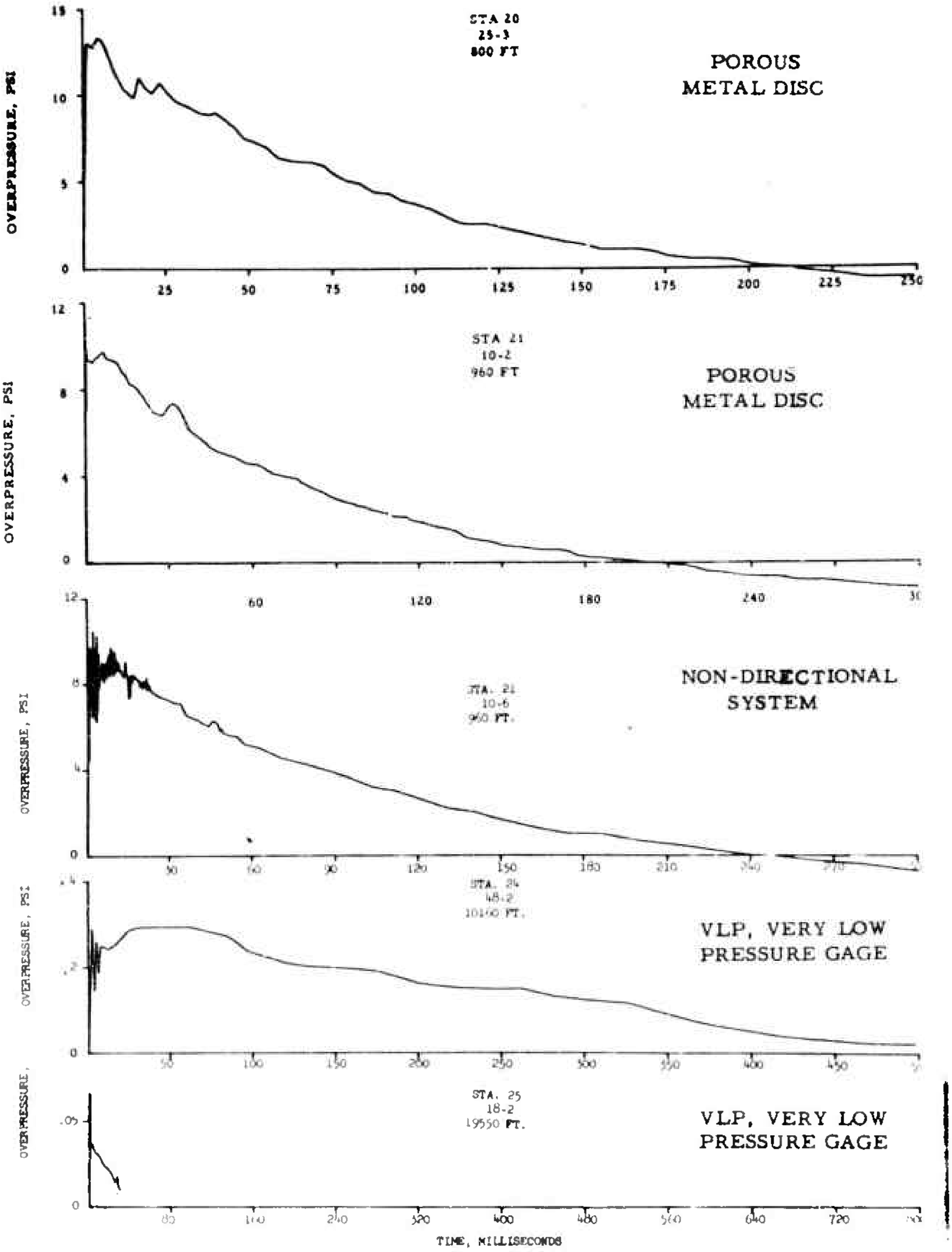

FIGURE 18. PRESSURE VERSUS TIME PLOTS, LOW PRESSURE REGION

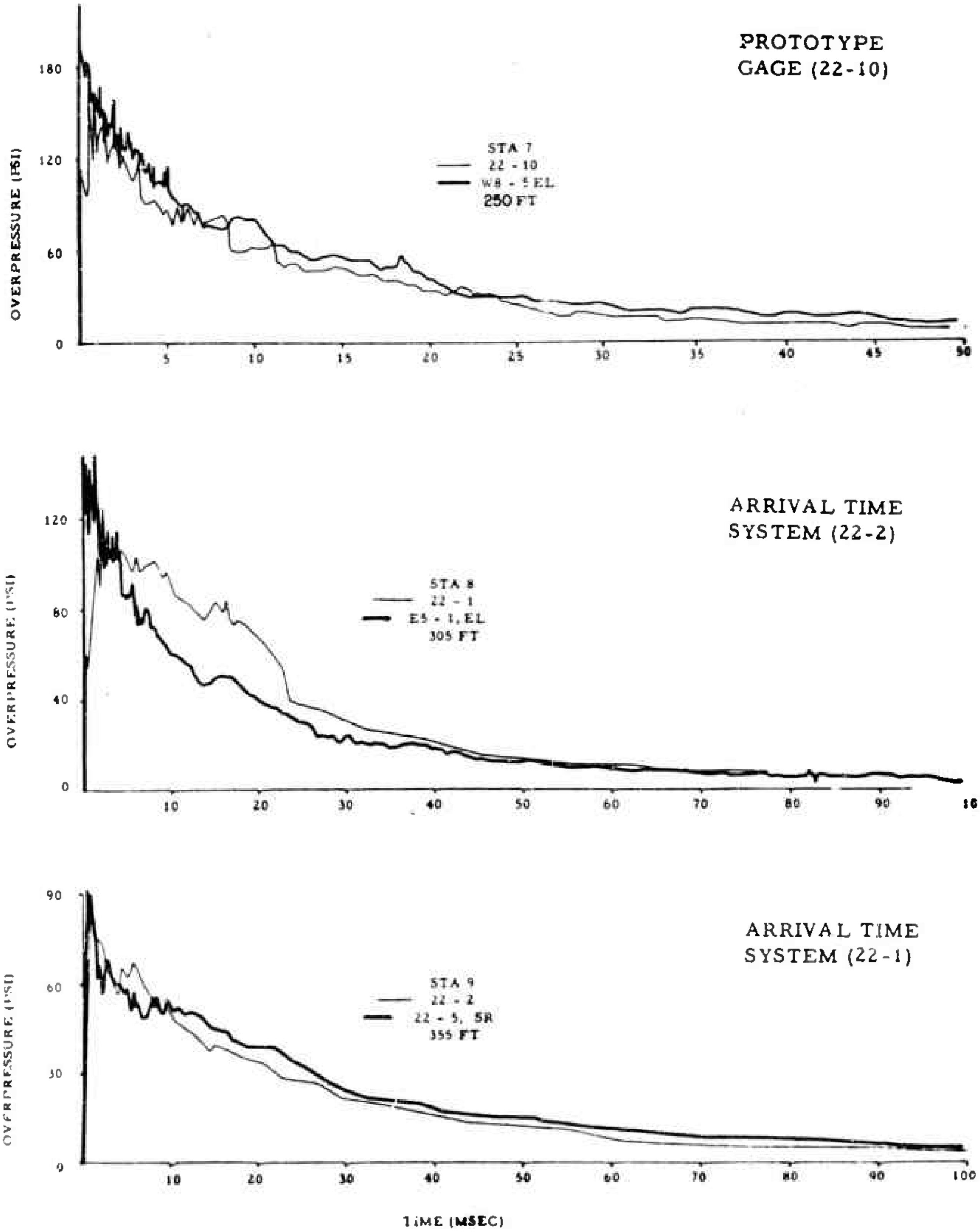

FIGURE 19. COMPARISON OF EXPERIMENTAL GAGE RESULTS WITH PROJECT 1.1 RESULTS

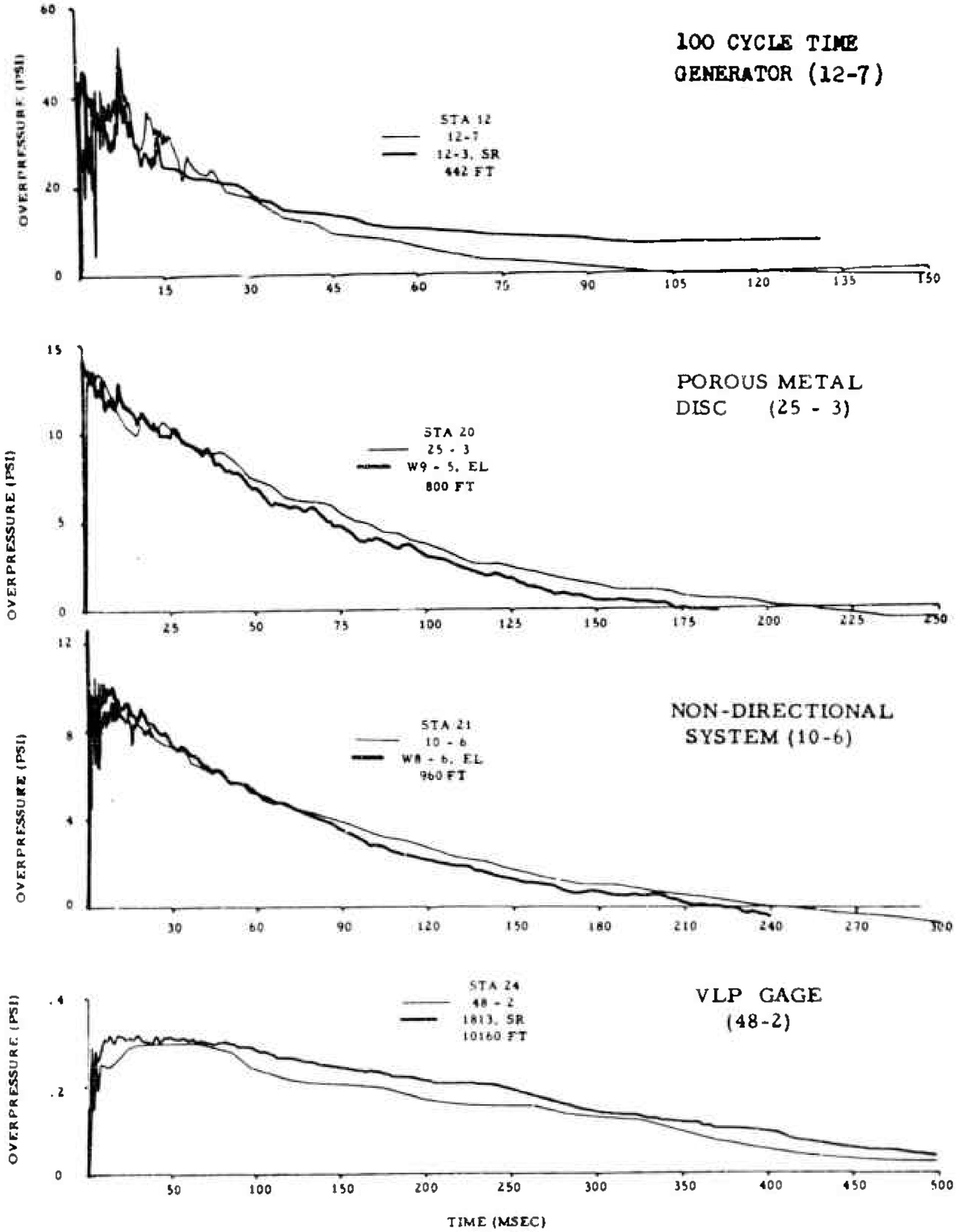

FIGURE 20. COMPARISON OF EXPERIMENTAL GAGE RESULTS WITH PROJECT 1.1 RESULTS

damping functioned well, gave good quality time traces, and yielded pressure-time values in good agreement with 1.1 data (Figure 20). The 60 percent dense disc at 800 feet and the 40 percent dense disc at 960 feet appear to be within proper range.

3.2.5 VLP Gage. The gage at the 10,160-foot station functioned well, produced a good time base trace, and the record was in reasonable agreement with 1.1 data (Figure 20). The gage at 19,550 feet operated for a short period and then failed due to motor trouble. Fortunately, the failure occurred after the arrival of the shock wave so that peak pressure was measured. The gage at 149,000 feet operated properly with a good quality time trace. No pressure signal was discernible, probably due to a lower-than-predicted pressure received at that range.

3.2.6 Prototype Accelerometer and Pressure Gages. All prototype gages performed reasonably well. The pressure-time values from two pressure gages are in good agreement with 1.1 data, and a comparison plot of the 245-foot gage results is shown in Figure 19. The record from the gage at 175 feet is of poor quality. The indicated overpressure value of 425 psi is not considered accurate enough to be used for a comparison in Figure 13. A detailed discussion of the results of all accelerometer and pressure gage prototypes is contained in the Appendix.

4. DISCUSSION

4.1 Nondirectional System

Results show that this particular type of sphere should be used in the 12 to 15-psi level. Further study is planned on the design of the sphere in order to damp out a 2200-cycle disturbance that appears in the plots of records from both gages (Figures 17 and 18). A mechanical fault in the time base generator of the gage at 630 feet caused a failure in the time trace following the arrival of the shock front. The time constant in the reduction of this record is based on an average cycle prior to the arrival time which may account for the 20 percent difference in duration and impulse.

4.2 Negative Pressure Gage

A 10-psi sensor is modified so that there is no deflection after 0.010 inches of movement in the positive direction. A bottoming plate, against which the sensor rests after its maximum deflection, is open in the center to allow the stainless-steel tubing to translate motion to the stylus. The failure occurred at the juncture of the tubing and diaphragm surface. A minor modification should avoid such a failure in the future.

4.3 Arrival Time Adapter

The zero-time adapter on the 305-foot gage fired prematurely, probably because of a stray reflection that signalled the photocell. It was impossible to trace the cause to the photocell assembly as it was destroyed in the blast. A comparatively high impulse is due to a perturbation in the 10 to 24-msec region of the decay. An examination of the gage and sensor gave no clue to the cause. The 355-foot gage functioned well in all aspects.

4.4 Modified Standard Gages

4.4.1 The 100-Cycle Time Base Generator. The impulse measurement from the 410-foot gage record is comparably high due to an unexplained perturbation in the 45 to 70-msec region of decay.

The 100-cycle system proved to have several weaknesses including a poor quality stylus which resulted in an illegible trace. The primary failure is in the mechanical design of the time marking oscillator. It is particularly vulnerable to acceleration in the vertical or most sensitive plane. A redesign of the time marker mechanism will be considered.

4.4.2 Porous-Metal Disc Orifice. Results from both gages is very encouraging. There was no evidence that any foreign matter passed thru the disc as is the general rule with all other damping media. The discs are easily flushed with a mild detergent. Further research in this area is under way.

Three independent photocell units at 800, 960, and 1450 feet functioned. These units had no time mechanism so it can only be assumed they fired at zero time.

4.5 VLP Gage

All three gages functioned. The motor in the 19,550-foot gage failed because of frictional drag between the recording drum and a guide bearing. Failure occurred a few milliseconds after the arrival of the shock front so that a peak value was recorded. The record from the gage at the 149,000-foot station did not show any deflection caused by pressure, although the gage did operate during the time it was exposed to air blast, and the record had a good quality time trace.

Microbarograph data has since shown that the pressure received at that range (SES Headquarters) was about 12 percent of that predicted. This pressure (0.0012 psi) would represent a displacement of something under 0.0015 inches on this VLP gage; such a displacement is impossible to locate on a 60-inch long trace and when found is difficult to evaluate. The conclusion is that this gage was out of range.

4.6 Prototype Accelerometer and Pressure Gages

A detailed discussion of the results of all the prototype gages may be found in the Appendix.

5. CONCLUSIONS

The requirements of Project 1.3b were fulfilled. Tests of this type are worthy of further consideration. Future development and test programs should improve the quality of self-recording instrumentation.

ACKNOWLEDGMENT

Appreciation, with extra emphasis for the field construction crew, is expressed for the excellent cooperation of all personnel at the Suffield Experimental Station.

Acknowledgment is extended to Mr. C. H. Hoover of the Ballistic Research Laboratories for his assistance in all phases of the prototype instrumentation.

DANIEL P. LEFEVRE

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APPENDIX

PROTOTYPE, SELF RECORDING INSTRUMENTATION TESTS

OPERATION SNOWBALL

FINAL REPORT

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PREPARED FOR

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Aberdeen Proving Ground, Maryland

CONTRACT NO. DA-36-034-AMC-0232(X)

THE BENDIX CORPORATION
FRIEZ INSTRUMENT DIVISION
Baltimore, Maryland 21204
PROJECT 32-0328

ABSTRACT

This report covers the participation by The Bendix Corporation, Friez Instrument Division in Operation Snowball during the period May-November 1964. The purpose of the Bendix Friez participation in Operation Snowball was to obtain field test data and experience useful in the design and development of self-recording blast instrumentation for Ballistic Research Laboratories. To accomplish the objective, instruments were manufactured in accordance with in-progress design studies; used in the Operation Snowball field test; and finally tested and evaluated in the laboratory. The report includes descriptions of the self-recording instruments, test information, and recommendations for improvements.

FOREWORD

The work described in this report was performed under the technical supervision of Messrs. R. E. Reisler and C. H. Hoover of the Explosion Kinetics Branch of the Terminal Ballistics Laboratory, Aberdeen Proving Ground, Maryland.

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A.1 INTRODUCTION

In December 1963, Bendix Friez was awarded R & D Contract No. DA-36-034-AMC-0232(X) to design, fabricate and test three each, prototype, ruggedized, self-contained, recording blast pressure gages and triaxial accelerometers for the Ballistic Research Laboratories, (BRL), Aberdeen Proving Ground, Maryland. A primary objective was the development of instruments capable of providing good records in environments associated with blast pressures above 200 PSI which is the limit for satisfactory performance of existing instruments. The contract specified a three phase program of study, fabrication and test in that order.

By May 1964 the study phase had progressed to a point where preliminary models of components had been made, including fluid oscillator timers (Reference 1) and blast pressure sensors. Development of a higher frequency electro-mechanical timer by a vendor, the Exline Engineering Company, showed promise. Bendix Research Laboratories had completed a design study for an accelerometer (Reference 2) and preliminary drawings based on the findings were in preparation at Bendix Friez.

Late in May 1964 the R & D contract was amended by Modification No. 1 which added Operation Snowball requirements to the existing work effort. Operation Snowball was a field test explosion of 500 tons of high explosives scheduled to take place in July 1964 at the Suffield Experimental Station, Alberta, Canada. The additional requirements imposed upon Bendix Friez by Modification No. 1 were as follows:

1. Manufacture three recording blast pressure gages based on latest design studies, for Operation Snowball field tests.

2. Manufacture three recording triaxial accelerometers based on latest design studies, for Operation Snowball field tests.

3. Pe[illegible] composite tests on the six instruments to insure properly functioning hardware prior to the field tests.

4. Provide field engineering service for the six instruments during Operation Snowball field tests.

5. Prepare a report on the performance of the instruments, together with conclusions and recommendations for improvements.

A.1.1 Background

During the period May - July 1964, i.e., the time between the issuance of Contract Modification No. 1 and the start of Operation Snowball field tests, three blast pressure gages and three accelerometers were built and tested. The designs were based on the R & D contract study phase developments as of May 1964. At that time, the design studies were not complete, particularly with respect to environmental conditions, as no shock or vibration tests had been performed. However, because of the short time available prior to the Operation Snowball field test, the use of these designs was justified on the grounds that the information to be gained from the field test would be of considerable value in furthering the design studies. In procurement, short cuts were taken to expedite delivery of components. For example, an available, large size, high pressure gas supply and pressure regulator package was purchased for the accelerometer timer, rather than wait for the development of a more compact assembly. After the blast pressure gages and accelerometers were assembled there was enough time to perform only a limited number of tests to demonstrate that the instruments were operating properly prior to delivery to the field test site.

The Pre-Snowball tests performed by Bendix Friez on a limited time schedule were the following:

1. Static pressure versus stylus deflection calibration of the three blast pressure sensors for the three blast pressure gages.

2. Operational tests of the three blast pressure gages:

    a. Recorder operation and adjustment of tape speed.

    b. Electro-mechanical timer operation.

    c. Adjustments to recording stylii to produce readable traces on the tapes.

    d. Electrical checks of all circuits.

3. Acceleration (centrifuge) versus stylus deflection calibration of the three accelerometers in three axes.

4. Operational tests of the three accelerometers:

    a. Recorder operation and adjustment of tape speed.

    b. Fluid oscillator timer calibration.

    c. Adjustments to recording stylii to produce readable traces on the tapes.

    d. Electrical checks of all circuits.

Under normal conditions, dynamic testing in the BRL Shock Tube would have followed the manufacturer's test program. Lack of time prior to the start of Operation Snowball field test necessitated the elimination of the dynamic tests. However, blast pressure sensors identical to those supplied in the Snowball instruments were tested in the BRL Shock Tube prior to the field test. The test results, presented in BRL Project 1.1 Report (Reference 3) provided a basis for confidence in using the new sensors in the Snowball field test.

The six instruments were delivered in July 1964. A representative from the Bendix Friez Engineering Department, assisted BRL personnel in servicing and maintaining the instruments during the Snowball field tests.

Following the field tests the instruments were returned for additional testing and evaluation. Post-Snowball tests and evaluation were not provided for in Contract Modification No. 1, but were conducted at the request of BRL as an aid in the design of the prototype instruments being developed under the original R & D contract. The Post-Snowball test and evaluation program consisted of the following items.

1. Visual inspection
2. Static pressure calibration of blast sensors
3. Shock tests of blast pressure gages
4. Vibration tests of the blast pressure gages
5. Shock tests of the accelerometers
6. Centrifuge calibration of the accelerometers
7. Vibration test of one accelerometer

The following pages of this report contain the details of the work done as outlined above, as well as conclusions and recommendations based on the work.

A.2 TEST INSTRUMENTS FOR OPERATION SNOWBALL

A.2.1 General

The six instruments comprised three self-recording blast pressure gages with ranges of 0-200 PSIG, 0-400 PSIG and 0-600 PSIG respectively; and three self-recording triaxial accelerometers, two with a range of 0-76G and one with a range of 0-20G (See Figures 1 thru 4). All six were self-contained, i.e., free from external power requirements. The instruments were designed to provide a visible (under magnification) record of blast pressure versus time or acceleration versus time on a steel tape. All six were designed to fit the BRL Type V ground baffle mount. The three blast pressure gages were also equipped with internal pipe thread adapters for optional pedestal mounting. Each instrument was equipped with a multi-conductor electrical cable for remote initiation and battery test.

A.2.1.1 Blast Pressure Gage

The blast pressure gage was a self-contained instrument designed to provide a record of blast pressure versus time on a steel tape. The Snowball instrument was a smaller and lighter gage than earlier models. Like previous gages, the Snowball gage was housed in a metal cylinder. However, aluminum alloy was used where possible and components were miniaturized to make an overall package 6-1/4" long by 4-3/4" diameter, weighing 5-3/4 lbs. The principal components of the blast pressure gage were (1) a blast pressure sensor, (2) a recorder and (3) a timer. In the Snowball gage the blast pressure sensor consisted of a 1-1/4" diameter Ni Span C convoluted disc diaphragm brazed to a stainless steel mounting plate. An osmium tipped stylus was mounted on a flat spring and attached to the center of the diaphragm by a short length of stainless steel tubing. Thus the deflection of the diaphragm was transmitted directly to the stylus. A jewel bearing surrounded the tubing supporting the stylus and restrained the stylus motion to a single axis. Specific improvements incorporated in the Snowball sensor included the following: (1) The sensor diaphragm was furnace brazed to the mounting plate to provide more uniform heating during assembly

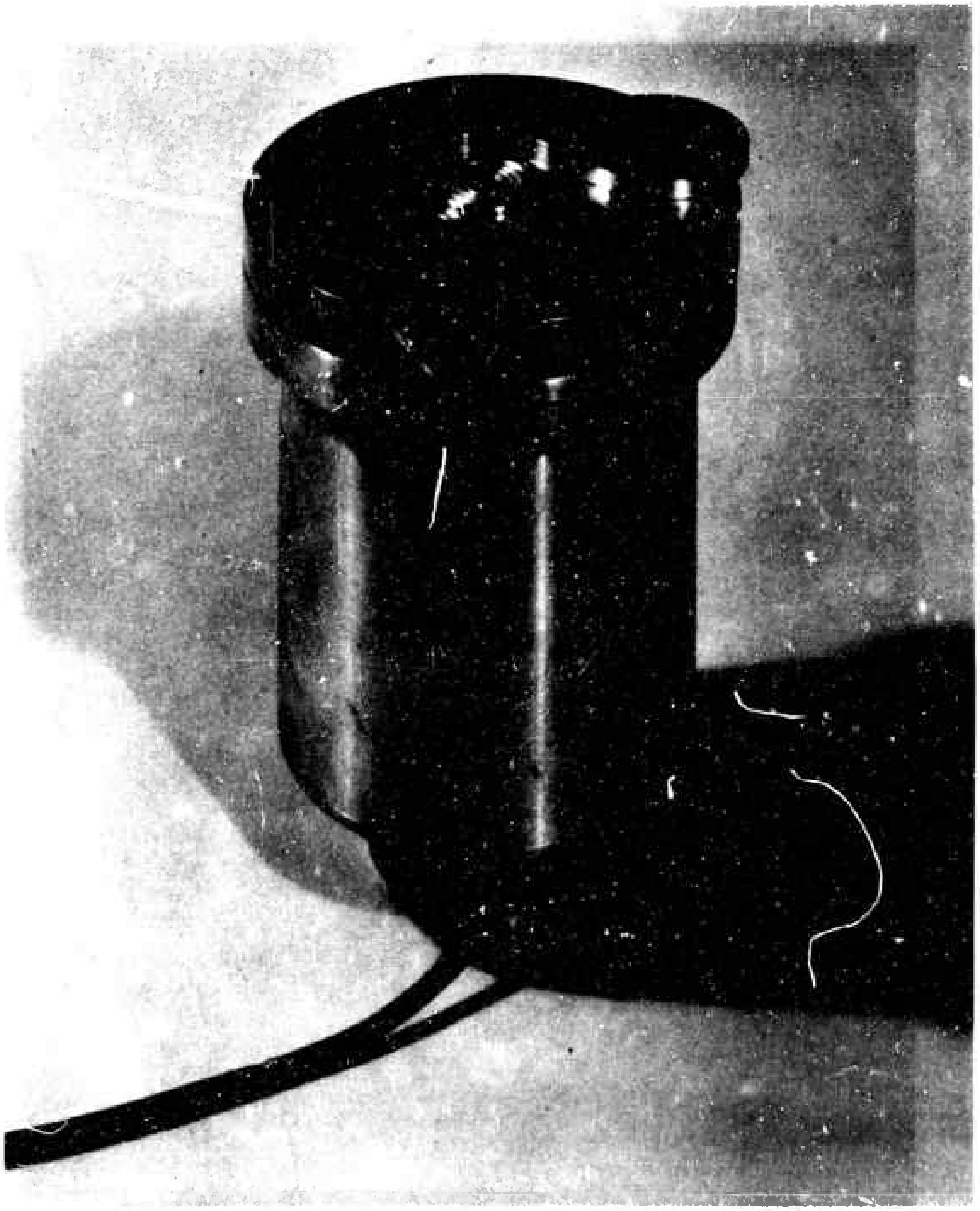


Figure 1 Blast Pressure Gage, Aperture Plate Removed to Show Sensor.

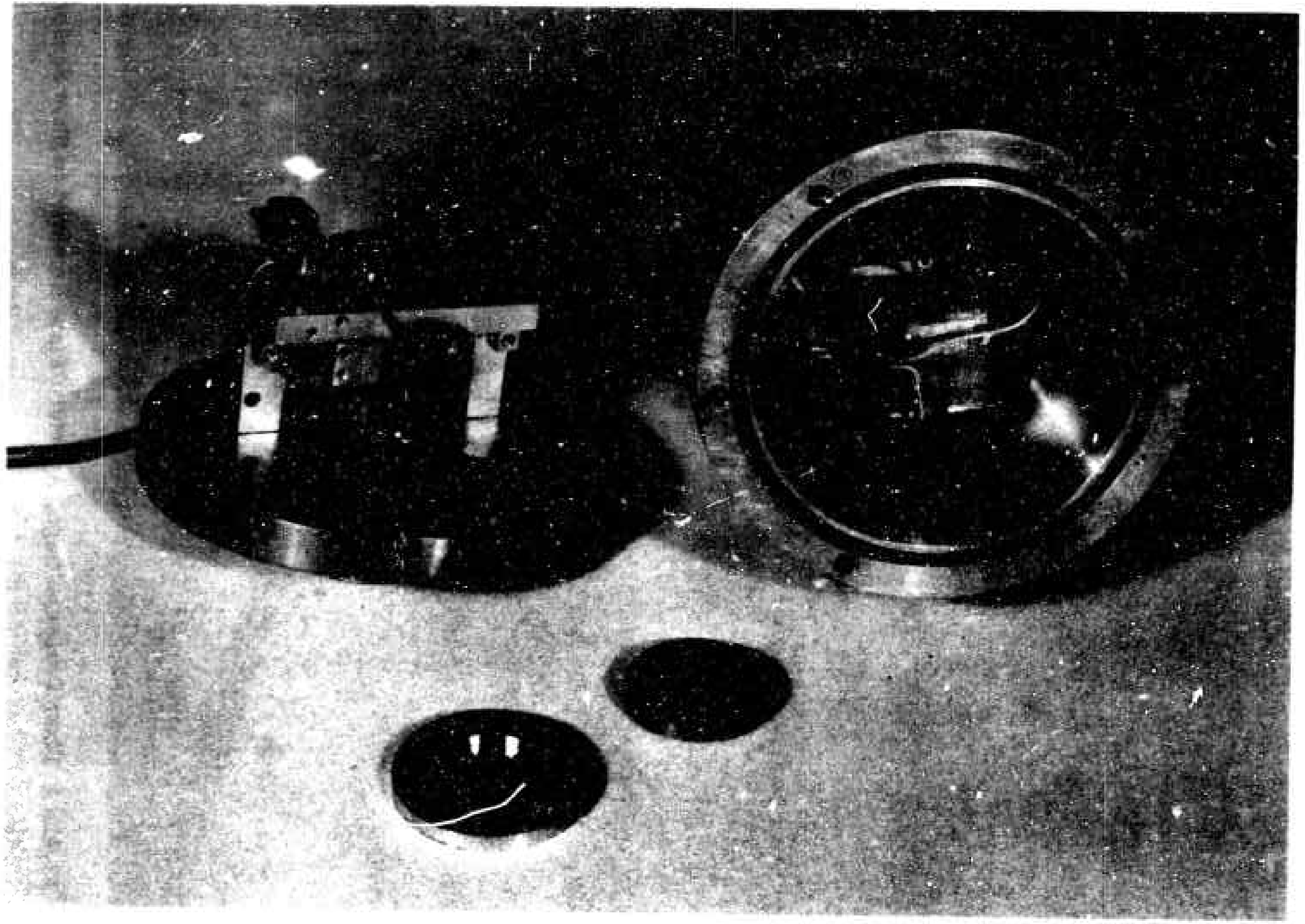


Figure 2 Blast Pressure Gage, Mechanism Removed From Housing. Aperture Plate and Blast Pressure Sensor in Foreground.

Figure 3 Triaxial Accelerometer Assembly.

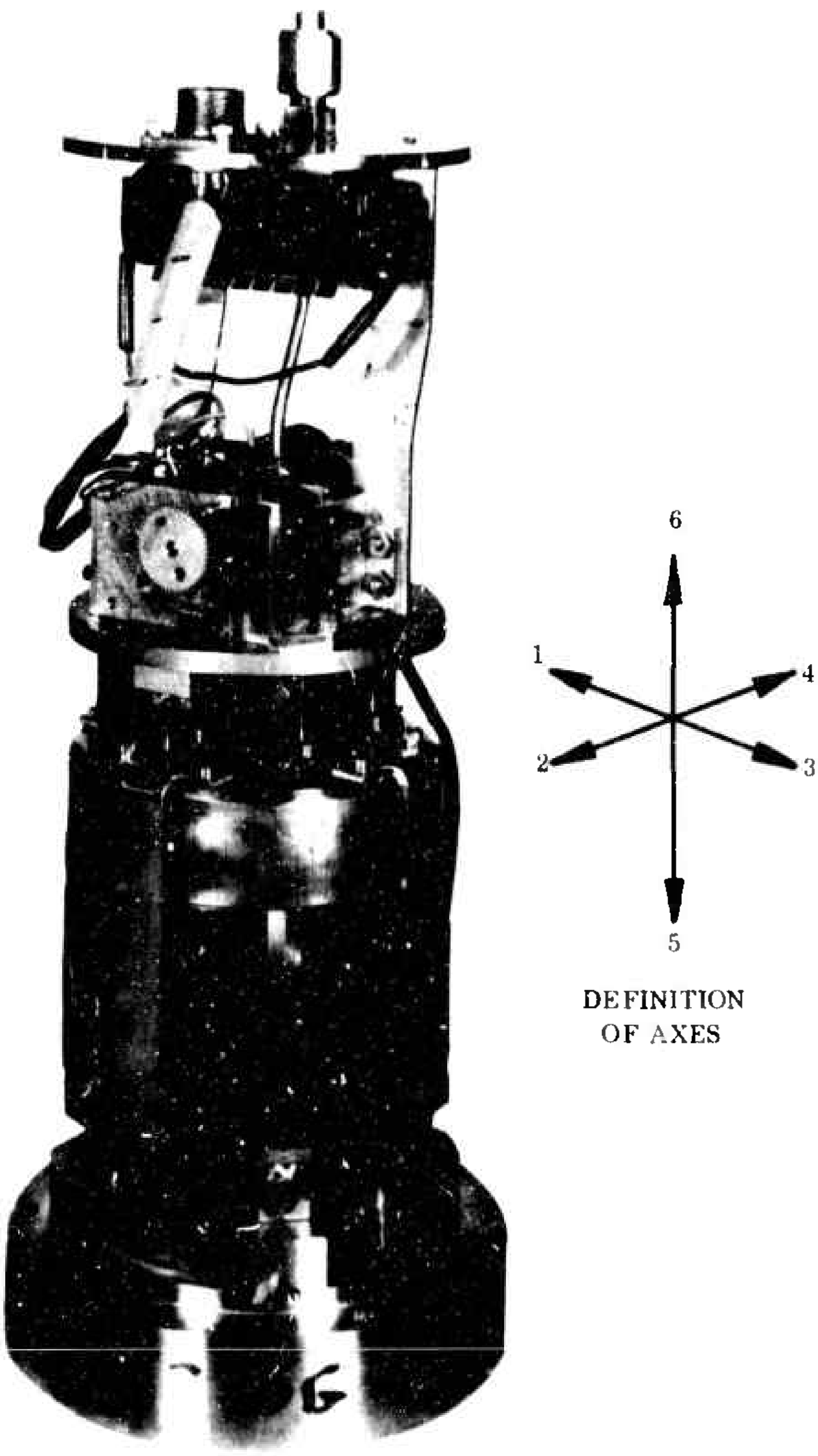


Figure 4 Triaxial Accelerometer. Housing Removed

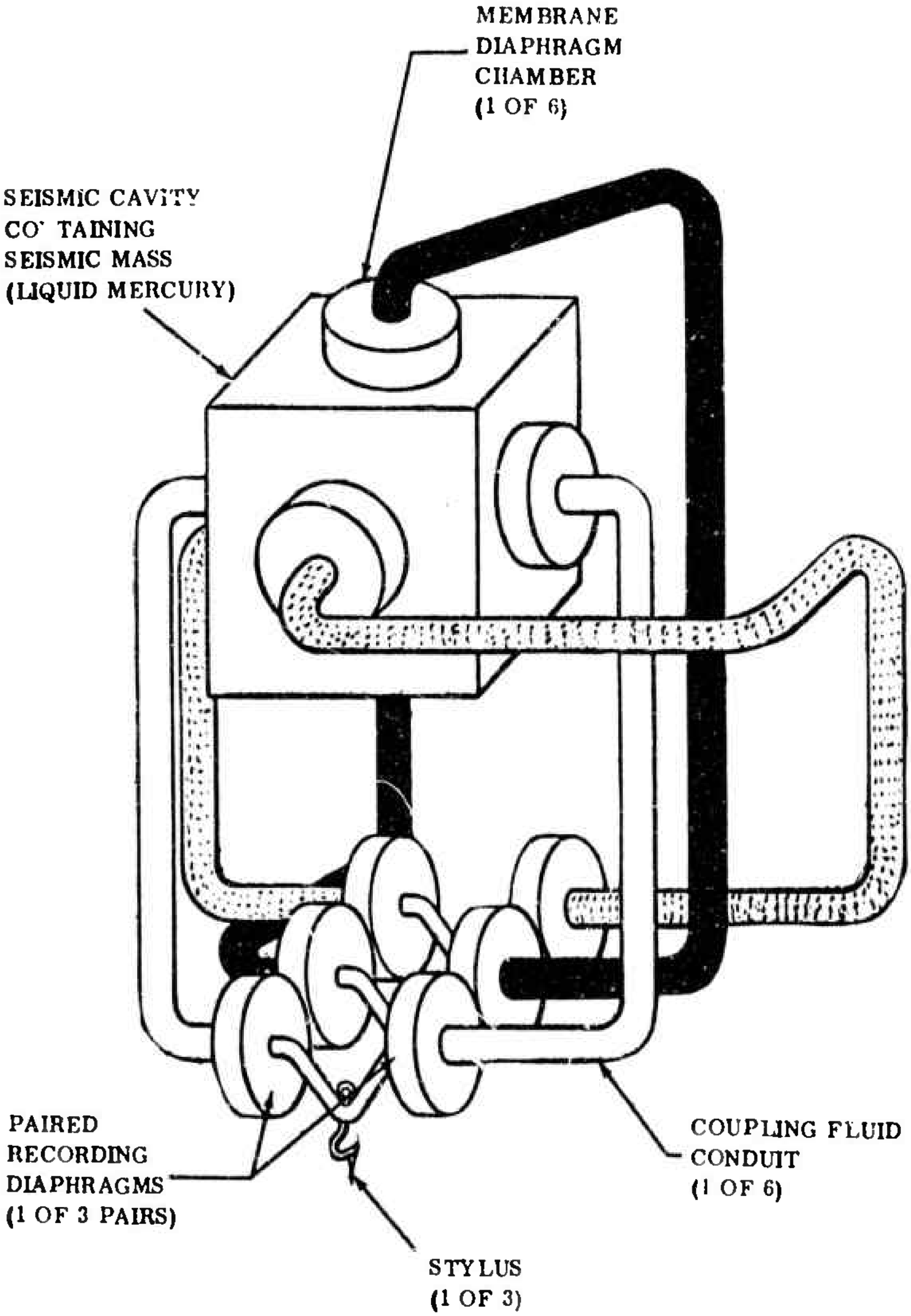


Figure 5. Schematic of Triaxial Accelerometer Sensing System

and eliminate strains within the diaphragm often caused by uneven heating associated with torch brazing. (2) The sensor assembly was made interchangeable with respect to the gage housing according to previously established procedures. This was made practical by means of dowel pin locators to align the sensor stylus in proper position with respect to the recording tape. (3) An O ring seal was provided between the sensor assembly and the gage housing. (4) The jewel bearing, previously mentioned, replaced a teflon bushing as the stylus guide. (5) The resonant frequency of the sensor assembly was raised to 3,500 cps or above for the 200 PSI to 600 PSI units.

The Exline recorder used in the Snowball gage was a smaller version of a similar recorder used in previous BRL gages. A stainless steel negator spring 3/8" wide by .0035" thick and about 60" long was used as the drive motor and the recording medium. The naturally convex face of the spring was vapor honed with a fine abrasive to produce a satin-finish, as a contrasting background for the stylus trace. The negator spring was wound up on a spool on the power output shaft. In unwinding, it passed over a flanged idler pulley in an arc of slightly less than 180° and on to a take-up spool. The stylii made contact with the spring at the idler pulley. A new feature in the Snowball recorder was the provision of a gear and slip-clutch drive between the power output shaft and the take-up spool to apply tension to the spring. This was an attempt to overcome the tendency, in earlier models, for the spring to leave the idler pulley under shock impulse and cause interruptions in the recorded traces. The recorder was equipped with a centrifugal-friction governor to control the angular velocity of the power output shaft. This in turn controlled the linear velocity of the spring to a nominal value of three inches per second. Actually, the linear velocity of the spring varied from 6% above average to 6% below average due to the continually decreasing radius of the point where the spring left the power output spool while unwinding. Another new feature in the Snowball recorder was the method of starting. An explosive piston actuator and rack-and-pinion were employed to impart an initial "kick"

to start the mechanism and bring the tape up to speed within five milliseconds (Reference 4).

The Exline electro-mechanical timer used in Snowball was developed from timers used in earlier BRL gages. The purpose of the timer was to provide a recorded time base for other events shown on the recorder tape. This was accomplished by vibrating a stylus at a known frequency, in contact with a moving tape to produce an oscillatory trace. Previously used electro-mechanical timers operated at a frequency of 50 cps. For Snowball, a higher frequency was desired. Under the basic R & D contract mentioned in the Background portion of this report, Exline Engineering Company was attempting to raise the frequency of the timer to the 250 cps range. Changes in the design of the timer, including smaller ball bearings, reduction in the moment of inertia of the rotor, an increase in the torque constant of the return spring, and control of contact bounce with biasing magnets had raised the frequency to 100 cps. Further increase in frequency was considered impractical within the limits of the basic timer design. The immediate need for a higher frequency timer for Snowball was met by a short cut and a compromise. The output from a 100 cps Exline timer, incorporating the changes noted above, was fed into a double pole double throw relay to vibrate the stylus mechanism at 200 cps.

Auxiliary components in the gage included a battery for powering the timer and to fire the piston actuator upon command, a manual arming switch and a fixed or reference stylus. Orifice damping as used by BRL on other self-recording gages was provided. The orifices may be seen in the aperture plates in Figures 1 and 2.

In operation, an external initisting switch attached to an electric cable connected to the gage is closed to fire the piston actuator, accelerate the recorder and start the timer. The piston actuator accelerates the tape to operating speed within five milliseconds. The tape runs for about twenty seconds. The three stylii (pressure, time and reference line) scribe separate traces simultaneously on the moving tape.

Test data is obtained from the blast pressure gage by removing the negator spring tape from the recorder and examining the stylii traces under magnification. Blast pressures are determined by comparing the deflection of the sensor stylus trace with appropriate pressure versus deflection calibration data. Time intervals are determined from the number of cycles of the known frequency traced by the timer stylus. The reference trace is normally a straight line. Any lateral motion of the tape with respect to the recorder frame would appear as an off-set in the reference trace.

A.2.1.2 The triaxial accelerometer may be described as a liquid mass, liquid coupled, self-damped recording instrument (See Figures 3, 4 and 5). All components except the high pressure gas supply and pressure regulator were housed within an aluminum alloy cylinder with a stainless steel cover and mounting plate. The overall dimensions were 11-1/2" long by 4-3/4" diameter at the mounting plate. The gas supply and pressure regulator were housed in a separate cylinder 5-1/2" long by 3-1/4" diameter. The two containers were connected by pneumatic tubing and an electrical cable. The combined weight of the two units was approximately 23 lbs.

The principal components in the accelerometer housing were (1) a liquid mercury seismic mass, housed within a roughly cubical cavity, with a Ni Span C membrane mounted on each of the six cavity walls, (2) six conduits containing the silicone fluid coupling liquid, starting at the outer surface of each of the six membranes and terminating at a Ni Span C diaphragm in each conduit, (3) a metal tube, carrying a stylus, connecting the outer surfaces of the diaphragms, in pairs, for each of the three orthogonal axes of the seismic cavity, (4) a spring-powered tape recorder in which a negator spring supplied the motive power and the recording surface, (5) a fluid oscillator timer operating a stylus at a calibrated frequency of approximately 500 cps, (6) a fixed or reference stylus, (7) a battery, (8) an explosive piston actuator and (10) a manual arming switch.

In operation, a remote initiating switch is closed to fire the explosive piston actuator to accelerate the tape recorder to normal tape speed within five milliseconds and start the regulated gas to flow to activate

SENSOR NO. 42-8

PRESSURE PSIG	DIAPHRAGM MOTION (DEFLECTION) INCHES	DIAPHRAGM HYSTERESIS (DOWN-UP) INCHES	COMPUTED MOTION (STRAIGHT LINE 0-400 PSI) INCHES	DEVIATION FROM COMPUTED MOTION INCHES	LINEARITY PER CENT BASED ON TOTAL DEFLECTION
0	0	-	0	0	0
100	.0040	-	.00414	-.00014	0.9%
200	.00812	-	.00828	-.00016	1.0%
300	.01230	-	.01241	-.00011	0.7%
400	.01655	0	.01655	0	0
300	.01232	+.00002	.01241	-.00009	0.5%
200	.00810	-.00002	.00828	-.00018	1.1%
100	.00400	0	.00414	-.00014	0.9%
0	0	0	0	0	0

Natural Frequency 5490 cps

TABLE I

PRE-SNOWBALL BLAST PRESSURE GAGE CALIBRATION

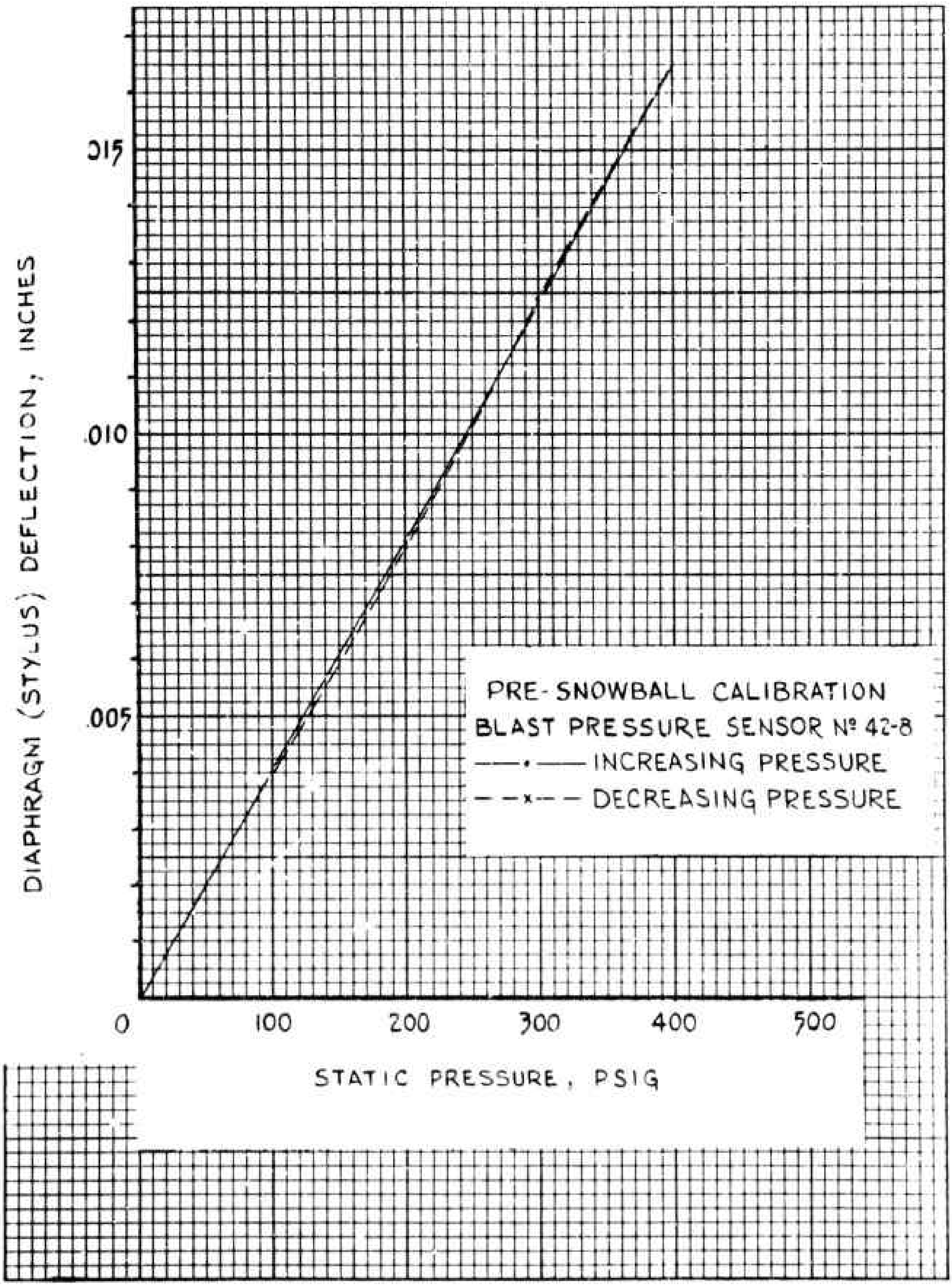


Figure 6 Pre-Snowball Calibration, Blast Pressure Gage.

the fluid timer. The recorder tape runs at about three inches per second for 20 seconds. Accelerations sensed by the instrument appear as deflections in the traces scribed on the tape by one or more of the three sensing stylii. At the same time the fixed or reference stylus and the timer stylus scribe respective traces on the tape.

The principle of operation of the sensing system may be described as follows: When the accelerometer is subjected to acceleration, the liquid mercury tends to move in the direction of the resulting force. Motion of the mercury deflects one or more pairs of membranes on the cavity walls and thus imparts motion to the silicone fluid in the coupling lines. The coupling fluid transmits motion to the diaphragms which, acting in pairs, deflects the attached stylii.

Data is obtained from the instrument by removing the tape from the recorder and examining the traces under magnification. Acceleration values are determined by comparing the observed deflections with calibration data. Time intervals are determined from the number of cycles of known frequency traced by the timer stylus. The reference trace serves as an indicator of tape stability.

A.2.2 Pre-Snowball Tests

Pre-Snowball tests were those tests performed on the three blast pressure gages and three accelerometers prior to installation in the field.

A.2.2.1 Blast Pressure Gages

The blast pressure sensors were calibrated by determining the static pressure versus diaphragm deflection relationship for both increasing and decreasing pressures. Pressure was applied to the sensor diaphragm by a dead weight tester and measured by a calibrated Heise gage. Deflections of the diaphragm were measured by a Carson electronic micrometer. Measurements were made in steps from zero to the maximum rated pressure of the sensor and back to zero. Calibration data for a typical sensor are shown in Table I. Figure 6 is a graphic presentation of typical sensor calibration data.

Operation of the complete blast pressure gage

assemblies was checked to insure (1) proper recorder tape speed of about three inches per second, (2) adequate stylii pressure to produce readable traces on the moving tapes, (3) proper electrical operation. The electro-mechanical timers were calibrated by the manufacturer, Exline Engineering Co., and the timer operating frequencies were reported as 201.04, 201.42 and 200.36 cps for the three units. When bench tested by Bendix Friez a variation in frequency of about $\pm$ 5% from the reported values was observed.

A.2.2.2 Triaxial Accelerometers

The accelerometers were calibrated by determining stylus deflection versus acceleration. To perform this test the accelerometers were mounted on the boom of a rotary accelerator (centrifuge) and subjected to various acceleration inputs in steps up to or slightly above the maximum rating of each unit on test. Recorder tapes were stationary during each step or run. Between runs the tapes were advanced about 1/2 inch to separate the individual traces and facilitate reading. Tests were made in one direction along each of the three orthogonal axes of the accelerometers. At the conclusion of the series of runs, the tapes were removed, examined under magnification, and the height of the deflection for each run was measured. The data for a typical accelerometer are tabulated in Table II and shown graphically in Figure 7. Other tests performed to insure properly operating units were as follows:

1. Calibration of fluid oscillator timer frequency (See Figure 8).

2. Measurement and adjustment to provide a recorder tape speed of about three inches per second.

3. Adjustment of stylii to produce readable traces on the moving tape.

4. Electrical check of all circuits.

A.2.3 Field Operations

During the Operation Snowball field tests, a representative of the Bendix Friez Engineering Department was present at the test site to provide field engineering service and to assist BRL personnel in servicing and maintaining the blast pressure gages and accelerometers.

ACCELEROMETER NO. 1X-76G

ACCELERATION G	AXIS SEE FIG. 4	STYLUS DEFLECTION INCHES	COMPUTED DEFLECTION (STRAIGHT LINE) INCHES	DEVIATION FROM COMPUTED DEFLECTION INCHES	LINEARITY PER CENT BASED ON TOTAL DEFLECTION
0	5-6	0	0	0	0
21	5-6	.0015	.0018	-.0003	[illegible].3%
42.1	5-6	.0035	.0035	0	0
63.2	5-6	.0050	.0053	-.0003	4.3%
84.3	5-6	.0070	.0070	0	0
0	4-2	0	0	0	0
20	4-2	.0010	.0014	-.0004	7.3%
40	4-2	.0030	.0028	+.0002	3.6%
60	4-2	.0040	.0041	-.0001	1.8%
80	4-2	.0055	.0055	0	0
0	1-3	0	0	0	0
20	1-3	.0007	.0013	-.0006	12.0%
40	1-3	.0020	.0025	-.0005	10.0%
60	1-3	.0035	.0038	-.0003	6.0%
80	1-3	.0050	.0050	0	0

TABLE II

PRE-SNOWBALL TRIAXIAL ACCELEROMETER CALIBRATION

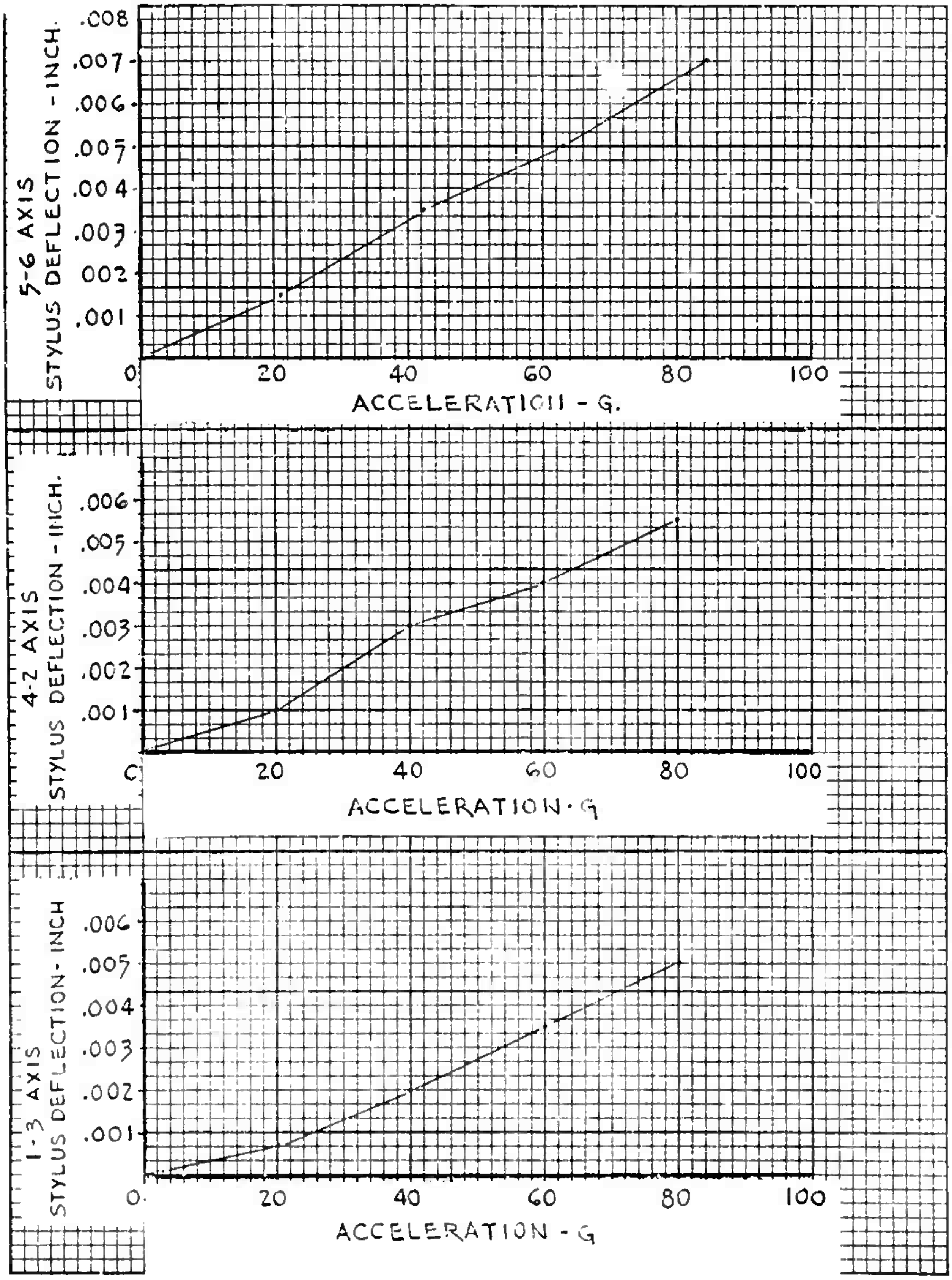


Figure 7 Pre-Snowball Calibration, Triaxial Accelerometer

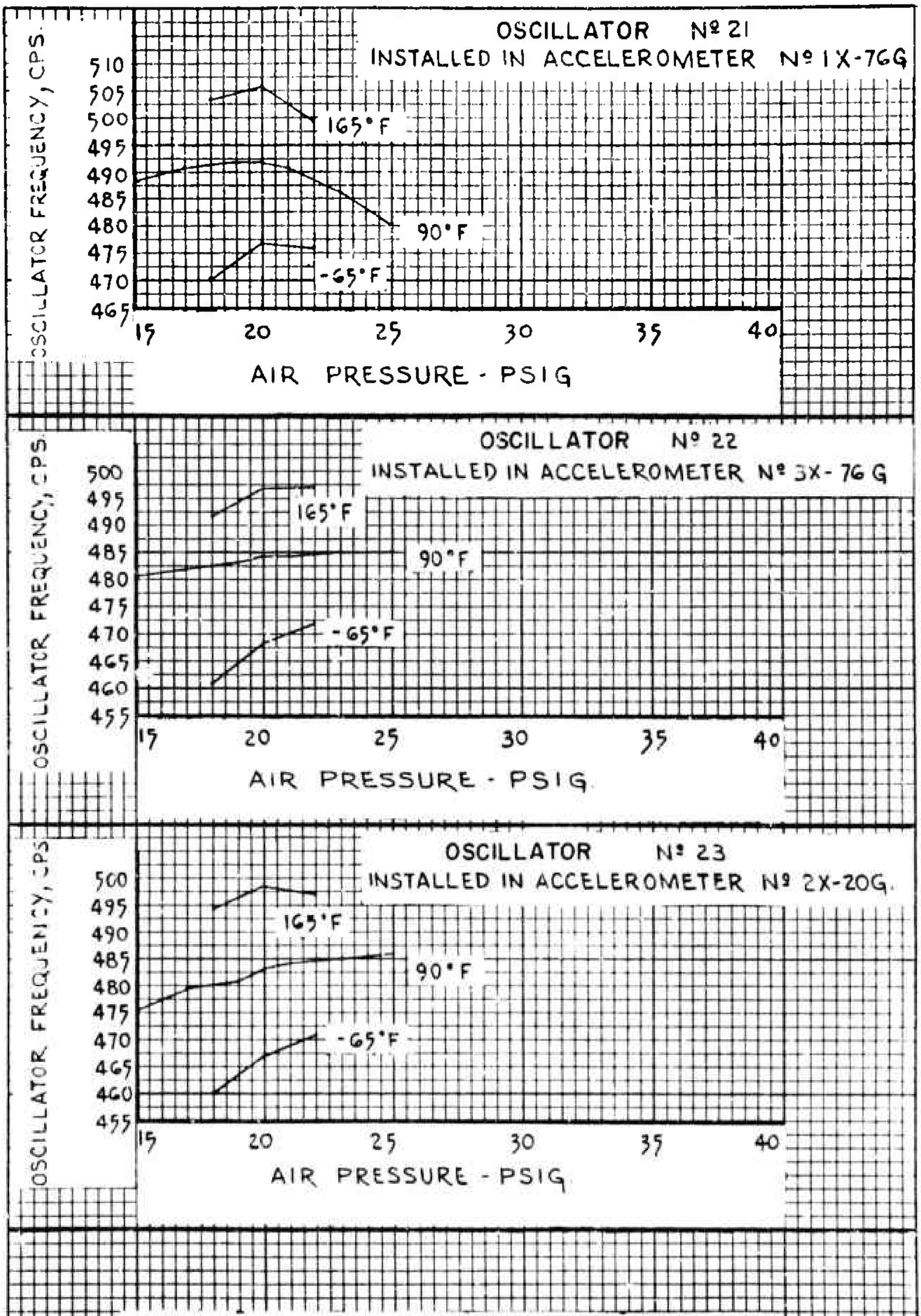


Figure 8 Fluid Oscillator Calibration Curves.

Operating tests were performed at the test site prior to field installation by initiating the piston actuators and running test tapes through the recorders. One fluid oscillator was operated from the compressed gas supply attached to the accelerometer. Following these tests, new piston actuators, tapes and compressed gas supply were installed as required.

The blast pressure gages and accelerometers were mounted on steel rings, encased in concrete with the top surfaces flush with ground level at designated positions with respect to Ground Zero as shown in Table III. About three hours prior to the detonation, the blast pressure gages and accelerometers were manually armed. The instruments were initiated at Zero Time minus two seconds by a relay closure in the Test Director's logic unit.

STATION	DISTANCE FT.	SENSOR	RANGE	SENSOR NO.
5	175	Pressure Gage	0-600 PSI	62-6
5	175	Accelerometer	0-76G	1X-76G
6	205	Pressure Gage	0-400 PSI	42-8
7	250	Pressure Gage	0-200 PSI	22-10
7	250	Accelerometer	0-76G	3X-76G
9	355	Accelerometer	0-20G	2X-20G

TABLE III

LOCATION OF INSTRUMENTS IN FIELD TEST

A.3 RESULTS AND DISCUSSION

As soon as permissible after the blast, personnel re-entered the area and recovered three of the instruments. The other three instruments were buried by the blast and were not recovered until later.

Enlarged photographs of some of the records produced by the instruments during the field test are shown in Figures 9, 10 and 11. In all cases, the motion of the tape is from right to left, and the time sequence of events on the traces is from left to right in the photographs. It should be noted that the photographs in Figures 9, 10 and 11 are composites. That is, each trace was photographed separately and then assembled and rephotographed as a group, primarily to show a sample of the records produced by the self-recording instruments in the field test. Because these are composite photographs the time of events on the respective traces may not be in exact alignment with each other.

Figure 9 shows a fairly good set of blast pressure gage traces and Figure 10 shows a poor set. Figure 11 is typical of the accelerometer recordings, all of which were rather poor.

Figure 9 is an enlarged (approximately 50X) photograph of the three traces recorded by the 200 PSI blast pressure gage. The bottom trace is that of the pressure sensor. The straight, horizontal line, representing ambient pressure prior to the blast, is clearly shown coming in from the left edge of the picture. Then there is a very rapid rise in pressure, with a small discontinuity in the vertical trace, as the gage senses the blast pressure. At the peak pressure and during the pressure decrease there are several loops in the trace, indicating tape reversals. The middle trace, the timer record, is readable, with perhaps not more than two or three timing marks missing during the blast interval. The heavy marks on the tape are deep indentations apparently made by the stylus during the blast period. Tape reversal is indicated since these marks overlap previous markings. The top trace is the reference line. Tape reversal is indicated by the loop in the trace. This is followed by some discontinuity in the trace. Otherwise the reference line is fairly stable and readable.

Figure 10 is an enlarged (approximately 95X) photograph of the three traces produced by the 600 PSI blast pressure gage. The bottom trace is the pressure sensor recording. To the left of the left edge of the picture (not shown) the trace was a horizontal line representing ambient pressure prior to the blast. At the left margin of the photograph the trace shows a rapid rise in pressure as it records the blast. After reaching a peak and starting down, the stylus apparently left the tape.

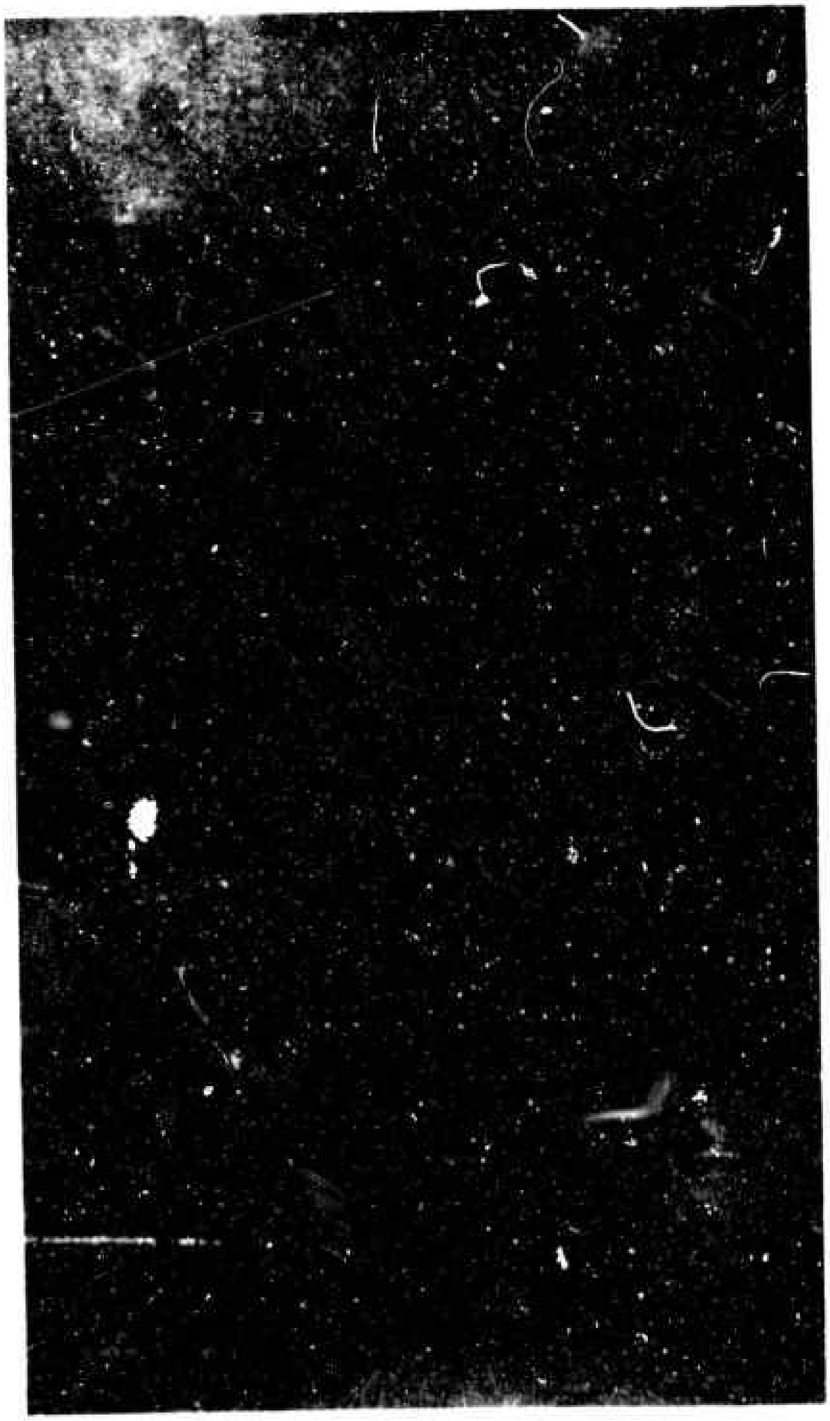
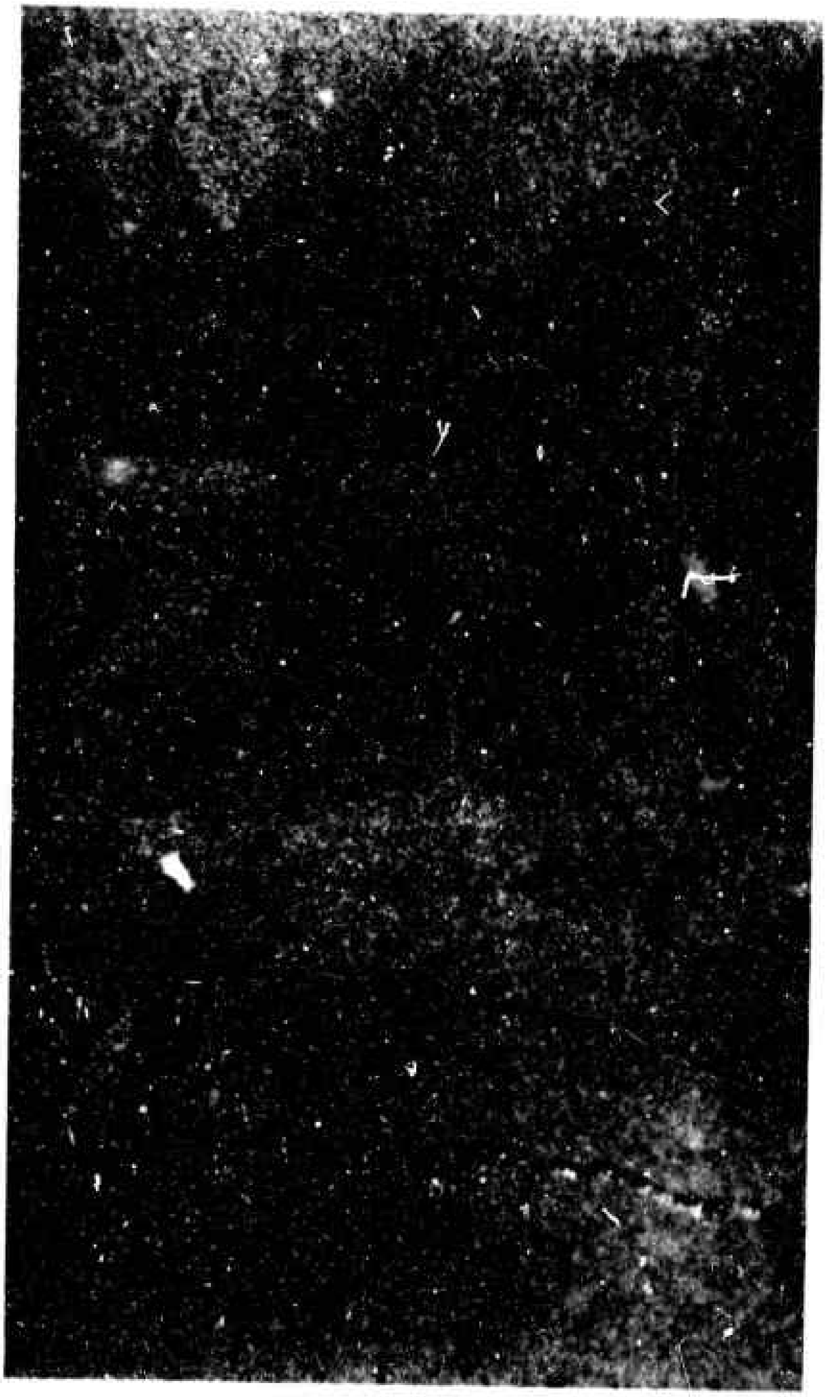


Figure 9 Blast Pressure Gage Traces, Showing Fairly Good Field Test Records



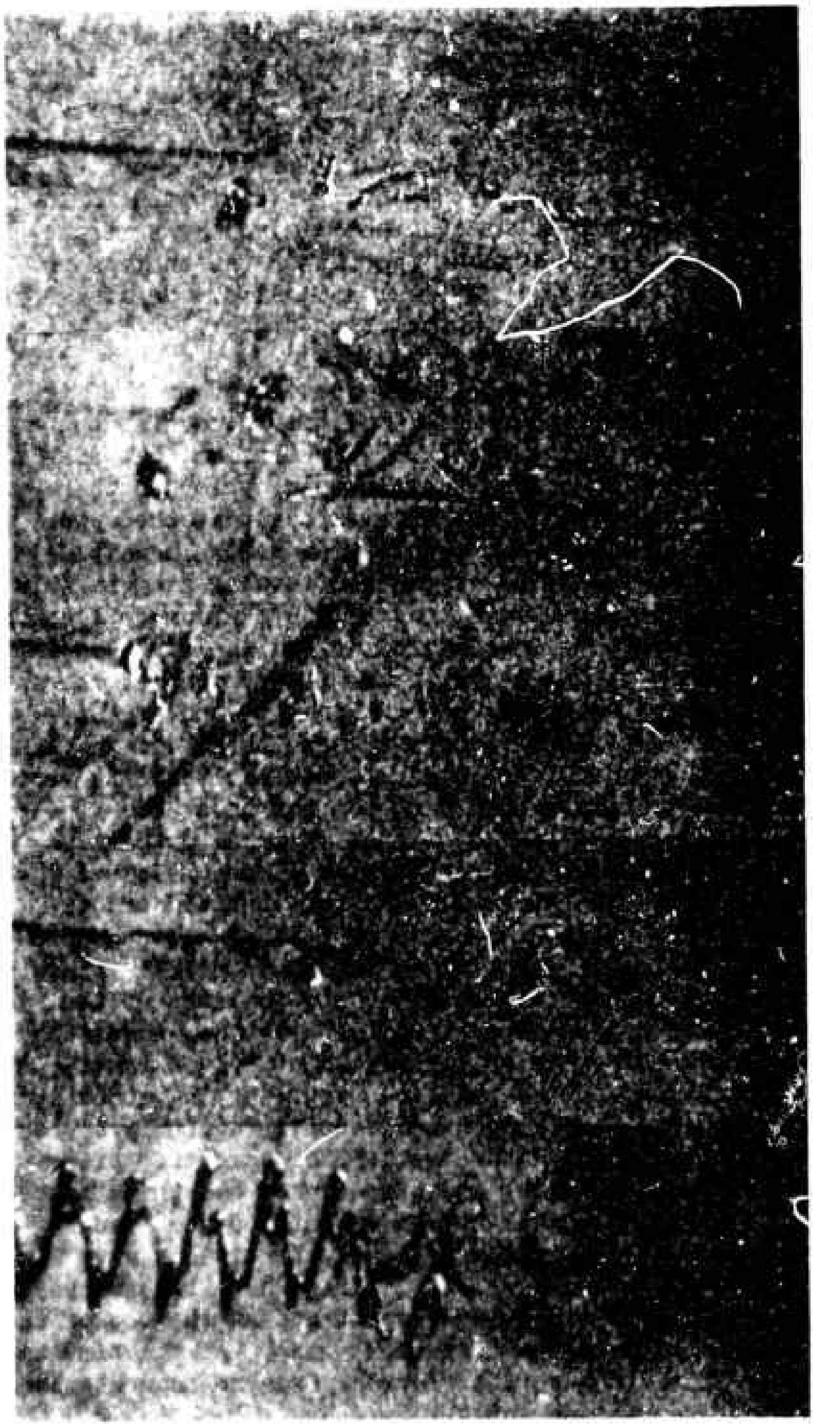
REFERENCE
TRACE

TIMER
TRACE

PRESSURE SENSOR
TRACE

←TAPE MOTION

Figure 10 Blast Pressure Gage Traces, Showing Poor Field Test Records.



REFERENCE TRACE

1-3 AXIS TRACE

5-6 AXIS TRACE

2-4 AXIS TRACE

TIMER TRACE

← TAPE MOTION

Figure 11 Triaxial Accelerometer Traces, Showing Typical Field Test Records.

A tape reversal seems to have occurred, for the trace resumes at an "earlier" time on the tape. The backward slopes and loops in the remainder of the trace indicate additional tape reversals. The middle trace is the timer record. Prior to sensing the blast the trace was similar to the timer trace shown in Figure 9. (The difference in magnification between Figures 9 and 10 should be noted.). Probably three timing marks are missing during the pressure sensing period and random stylus marks appear instead. The finger-shaped trace at the right of the photograph is a somewhat distorted timing mark. Beyond, to the right and not shown, the timing marks resume a normal pattern. The reference line at the top of the photograph shows considerable evidence of tape reversal and shift. Shift is defined as motion at right angles to normal tape travel.

Figure 11 is an enlarged (approximately 50X) photograph of the five traces recorded by one 76G accelerometer. The timer trace at the lower left corner of the picture shows five very similar, but distorted figures representing the timer oscillations, prior to the blast. The principal deviations in the figures occur at the upper extremities where there is a noticeable variation in the magnitude of stylus deflection. There is also evidence of stylus drag in this region. For example, after the stylus reached its maximum deflection upward, the return stroke should have angled off to the right on the tape. Instead, the return stroke tends to parallel the up stroke as though dragged sideways by the moving tape. Finally, the stylus breaks free, traces a "V" and then resumes a normal stroke down and to the right. During the time of the blast, the timer trace is very erratic, there is no regularity in the patterns and there are discontinuities. Also, there is evidence of tape reversal or perhaps stylus drag where traces overlap or show reverse slopes. Beyond the right edge of the picture, but not shown, the same pattern of distorted, but similar timing marks, shown at the left edge of the picture, resumes after the blast. The second, third and fourth traces from the top represent the three acceleration sensing axes of the accelerometer. All three traces exhibit similar, but not identical characteristics. The traces enter the picture at the left margin as straight or nearly straight, horizontal lines representing a steady state. (The trace for axis 2-4 shows a series of irregularly spaced deflections of very low magnitude and duration for some time prior to the sensing of the blast). When the blast is sensed all three traces are very erratic. The traces appear as random dots, dashes and segments of curves followed by continuous or nearly continuous wavy lines. There is evidence of tape reversal or stylus drag where traces overlap, repeat or show reverse slopes. The reference trace at the top of the picture, enters at the left edge as a straight line. At the time the blast is sensed, the trace is a series of widely spaced segments showing evidence of tape reversal and shift.

To sum up the general impression gained from the photographs, it is

obvious that more stability in the instrument structure is essential. Tape reversal and tape shift call for better recorder design. Discontinuities in the traces probably indicate relative motion of the recorders with respect to the mounting plates, or bounce in the stylii supports.

Figure 12 shows smoothed pressure versus time plots of the field test data obtained from the three blast pressure gages. These plots are the result of curve smoothing by BRL to correct the recorded traces for defects such as tape shift and tape reversal.

A.3.1 Post-Snowball Tests Blast Pressure Gages

Post-Snowball tests are those tests performed on the blast pressure gages and accelerometers after the Snowball field tests were completed and after the instruments were returned to the plant.

A.3.1.1 Visual Examination

Two of the blast pressure gages (400 and 600 PSI units) were visually examined upon return from the Snowball field tests. All breaks in the external surfaces of the gages, such as cap screw recesses, sensing apertures and switch cavities had been filled with fine sand. Sufficient sand had worked through the sensing holes in the aperture plates to produce small "sand-blasted" crescent shaped markings on the surfaces of the pressure sensor diaphragms. When all the sand was removed, however, there was no visible evidence of damage to the external surfaces of the blast pressure gages. From a structural point of view, two of four screws in one aperture plate were loose.

Inside the blast pressure gages there was very minor damage. For example, the piston actuator stop block on both recorders had moved slightly out of position. This probably occurred when the actuator was fired to start the recorder. End play was observed in the pinion shaft of one recorder and in the intermediate gear shaft on the other recorder. On both blast pressure gages the pressure sensing stylus was bent in the direction of tape motion.

A.3.1.2 Static Pressure Calibration

All three blast pressure sensors were recalibrated as a check on the pressure versus deflection characteristics after exposure to the field tests.

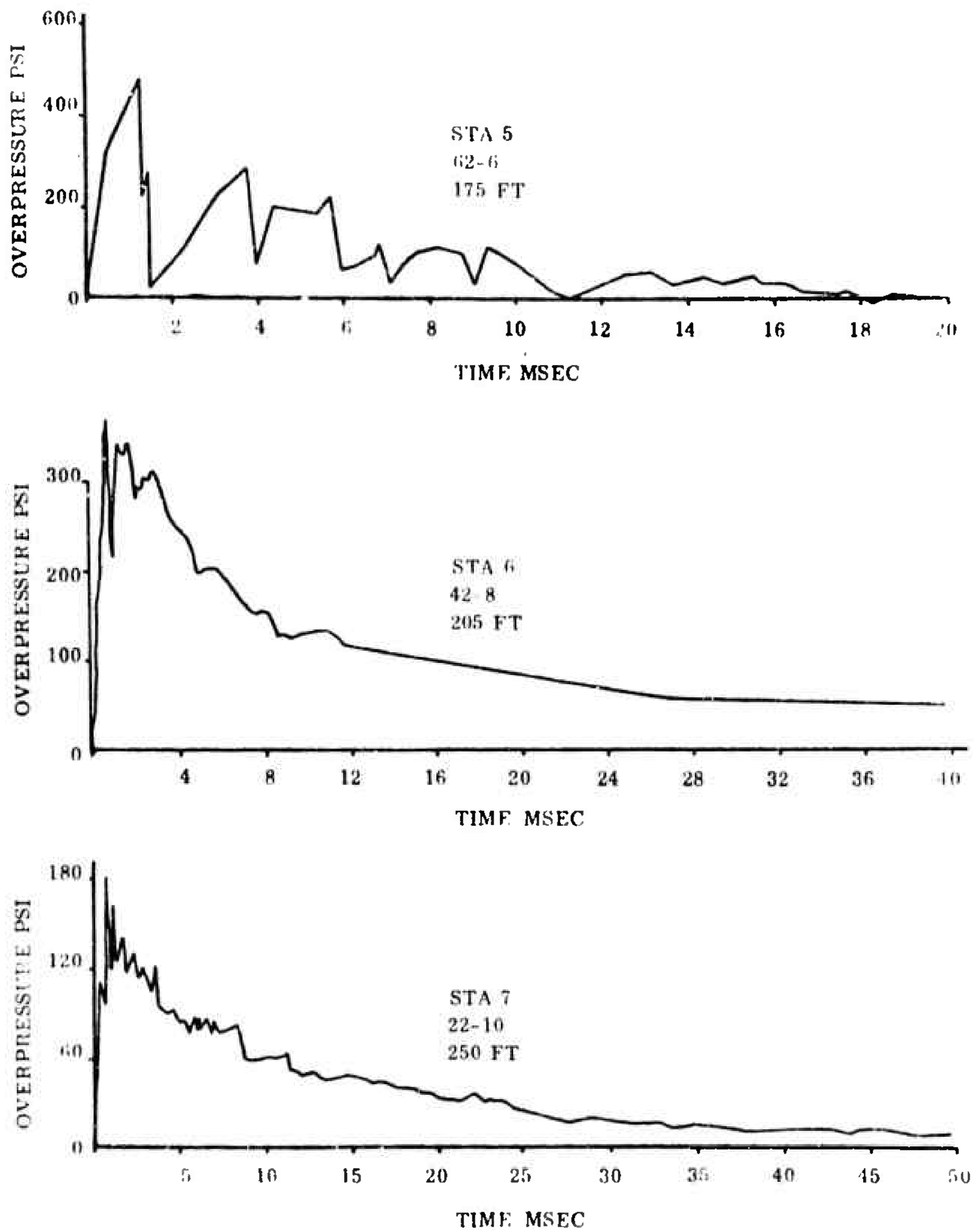


Figure 12 Field Test Pressure-Time Plots

The method of calibration was identical to that employed in the Pre-Snowball tests. A comparison of the "pre" and "post" Snowball calibrations for one typical blast pressure sensor is shown in Figure 13. The two sets of data for the three blast pressure sensors show good agreement at all corresponding test points. The maximum difference at any one calibration point was 1.8% based on total motion of the blast pressure sensor.

A.3.1.3 Shock Tests

All three blast pressure gages were tested to determine the behavior of the blast pressure gage mechanism under shock conditions. Each blast pressure gage was fastened, in turn, to the table of a Barry Model 20 VI sand drop machine and subjected to shock pulses of 25, 50 and 100G with a pulse duration of 10 to 12 milliseconds. All drops were made in the vertical axis with the blast pressure sensor facing downward. The recorder tape within the blast pressure gage was running during the tests.

Following the drops the recorder tapes were removed, photographed under magnification and evaluated. The data are tabulated in Table IV. A total of 11 drops were made, four at 25G, three at 50G and four at 100G. Only the blast pressure sensor trace was visible on the tapes for all 11 drops. The timer trace was not visible at all. The reference trace was visible in only four of the 11 drops. At 25G, the blast pressure sensor traces for three of the drops showed no deflection due to shock, while a pulse .0005" high was recorded in the fourth drop. At 50G, there was a pulse .0005" high in the blast pressure sensor trace for all three drops. At 100G there were three traces with a pulse .001" high and one with a pulse .0015" high (See Figure 14). Thus it appears that shock impulses up to 100G have little effect on the pressure sensing accuracy of the blast pressure gage. There was no evidence of structural damage to the blast pressure gages due to shock. The reference traces, when visible, showed no deviation from a straight line. In the Snowball blast pressure gages the reference stylus was mounted on the recorder frame. Therefore, the straight line traces produced in the shock tests merely indicated no lateral motion of the tape with respect to the recorder frame. Any motion of the recorder with respect to the blast sensor base plate was not indicated. A reference line stylus

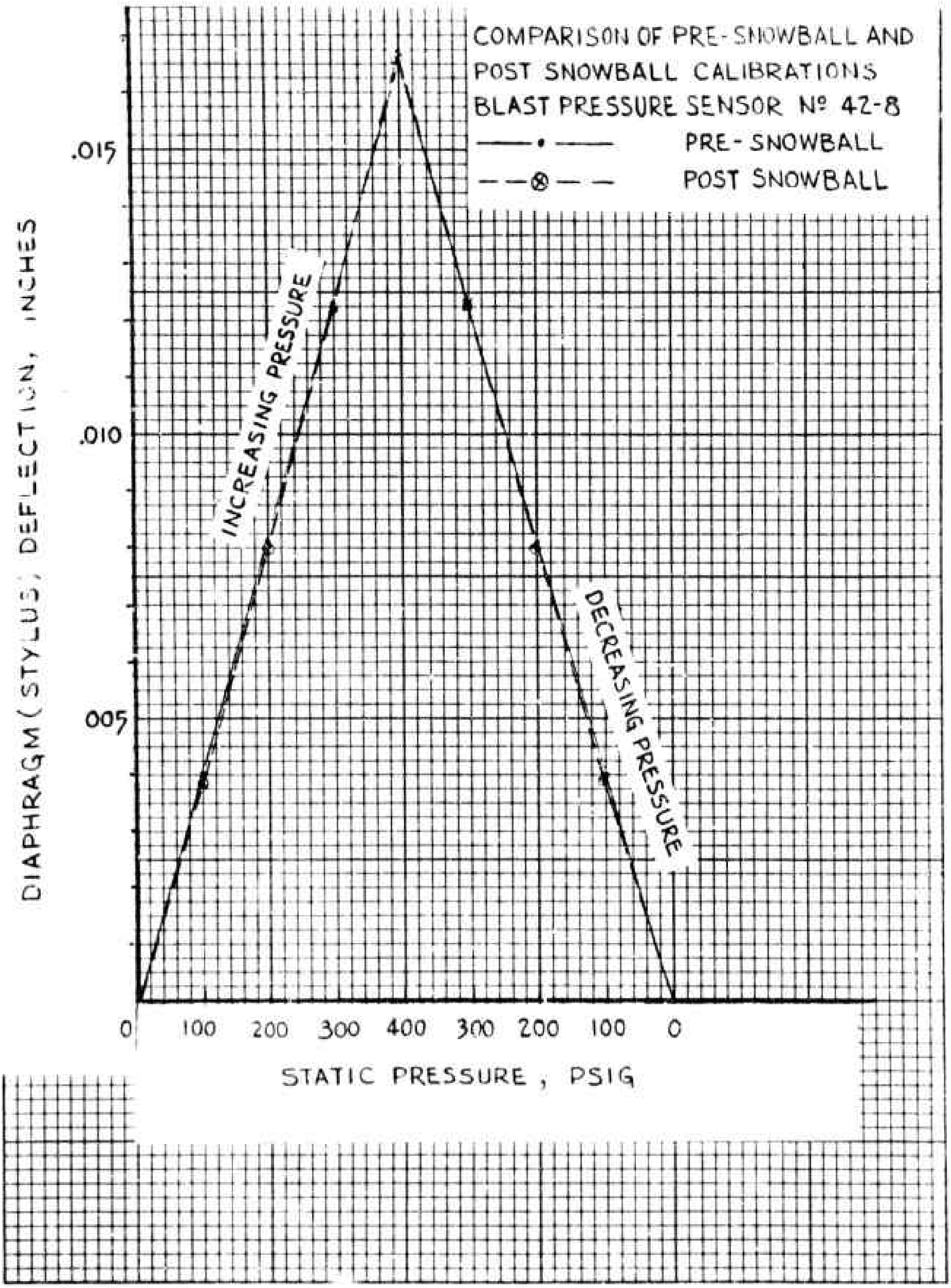


Figure 13 Comparison of Blast Pressure Gage Calibrations.

DROP NO.	BLAST GAGE UNIT PSI	SHOCK INTENSITY G	SHOCK PULSE DURATION MILLISECONDS	SENSOR FULL SCALE DEFLECTION INCH	STYLII TRACE OBSERVATIONS			
					SENSOR APPEARANCE	PULSE AS PER CENT OF FULL SCALE DEFLECTION	TIMER APPEARANCE	BASE LINE APPEARANCE
1	400	25	11	.01662	Straight Line	0	Not Visible	Straight Line
2	400	50	10	.01662	.0005" Pulse	3%	Not Visible	Discontinuous Straight Line
3	400	100	10	.01662	.001" Pulse	6%	Not Visible	Not Visible
4	600	100	10	.02057	.001" Pulse	5%	Not Visible	Not Visible
5	600	50	10	.02057	.0005" Pulse	2.5%	Not Visible	Straight Line
6	600	25	12	.02057	Straight Line	0	Not Visible	Not Visible
7	200	25	-	.03190	Straight Line	0	Not Visible	Not Visible
8	200	25	12	.03190	.0005" Pulse	1.5%	Not Visible	Not Visible
9	200	50	10	.03190	.0005" Pulse	1.5%	Not Visible	Not Visible
10	200	100	-	.03190	.001" Pulse	3.1%	Not Visible	Not Visible
11	200	100	11	.03190	.0015" Pulse	4.7%	Not Visible	Straight Line

TABLE IV

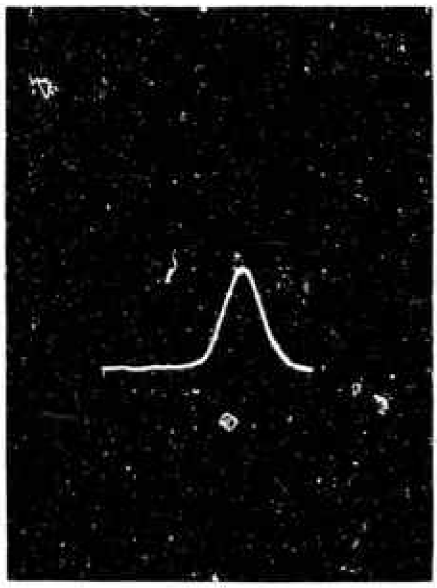
POST-SNOWBALL SHOCK TESTS OF BLAST PRESSURE GAGES

PRESSURE SENSOR TRACE

DEFLECTION:

APPROXIMATELY .001 INCH

← TAPE MOTION



INPUT SHOCK IMPULSE
Vertical Scale
25 G per division
Horizontal Scale
2 msec per division
Shock Intensity 100 G
Shock Duration 10 msec

← TIME

Figure 14 Deflection of Blast Pressure Gage Stylus in Response to Shock Test Impulse.

mounted on the blast pressure sensor base plate would provide more useful information, which could be used to correct the blast pressure sensor trace if a shift in the tape was indicated.

A.3.1.4 Vibration Tests

The three blast pressure gages were mounted, in turn, on the table of an M-B Model C-10 vibration machine to search for resonance points in the gage structure. Each gage was vibrated over a frequency range of 10 to 2000 cps at a constant input of 20G. The recording tapes in the gages were running during the tests. Details of the test conditions are tabulated below:

Run No.	Blast Gage Unit	Frequency Range CPS	Input G	Timing Stylus Operation
1	200 psi	10-2000	20	Not operating
2	200 psi	10-2000	20	Not operating
3	400 psi	10-2000	20	Not operating
4	400 psi	10-2000	20	Operating
5	600 psi	10-2000	20	Not operating

Observation of the recorder tapes following the tests showed that the blast pressure sensor trace remained a straight line at the lower frequencies. As the frequency approached 80 cps, the blast pressure sensor trace began to respond to the vibration at a double amplitude of about .001" to .002". As the input frequency increased above 80 cps the frequency of the response in the blast pressure sensor trace increased also. However, the amplitude of the oscillations remained essentially constant at about .002" double amplitude. The reference trace remained a straight line throughout the test. The timer stylus, when not operating, produced only a straight line in all cases except at the higher frequencies in run no. 3 where there was no visible trace. In run no. 4 the operating timer stylus produced a saw tooth trace of about .010" double amplitude.

A.3.2 Post - Snowball Tests, Triaxial Accelerometers

A.3.2.1 Visual Examination

Some deficiencies in the fluid oscillator design were apparent after a visual examination of the triaxial accelerometers returned to Bendix Friez from the Snowball field tests.

In one unit the lucite mounting plate of the oscillator had fractured, making the timer inoperative. In a second accelerometer the cemented joint between two plastic parts had failed. In addition the metal tubes attached to the plastic parts had worked looae.

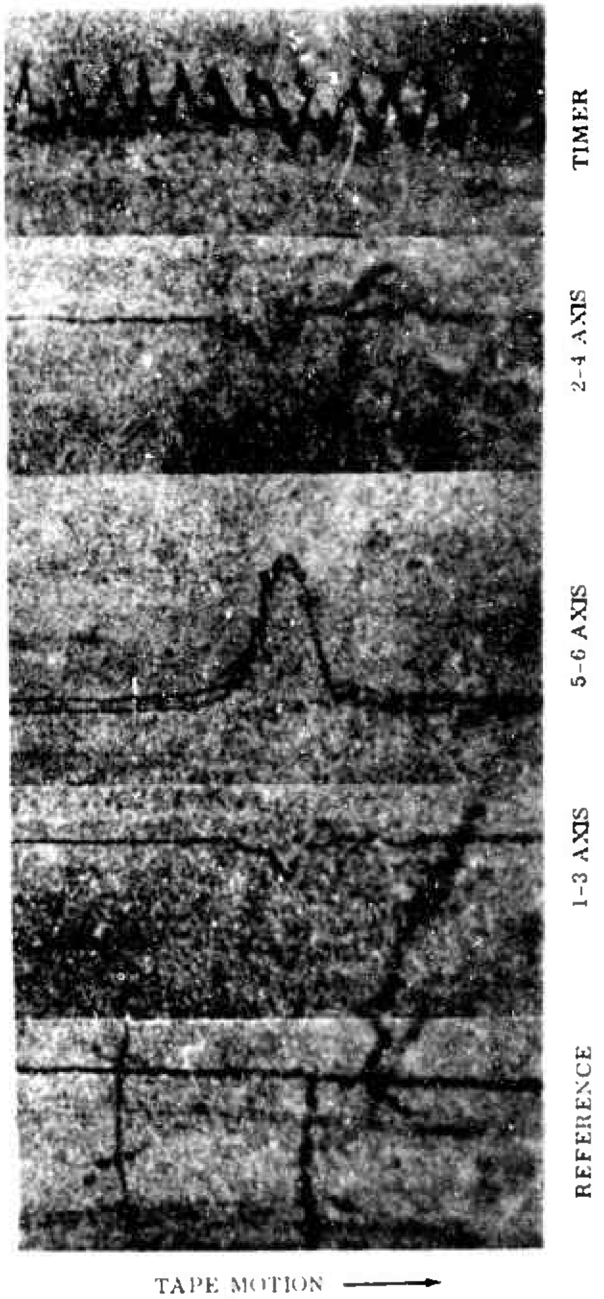
Later on in the test program, one accelerometer was disassembled. In this unit several of the membrane diaphragms were found to have been damaged by bottoming against the walls of the membrane chambers.

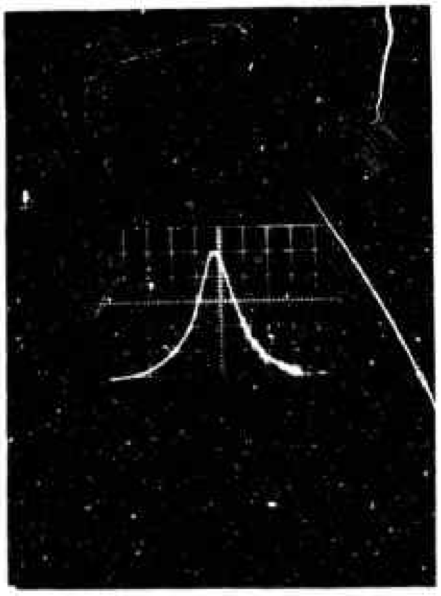
A.3.2.2 Shock Tests

All three accelerometers were subjected to a series of shock impulses ranging up to approximately twice the respective ratings. Tests on the two accelerometers rated at 76G were performed on a Bungee Cord "Slingshot" Shock Stand at 30, 60, 90, 120 and 150G with a pulse duration of 10 to 13 milliseconds. The 20G accelerometer was tested on the Barry Model 20VI sand drop tester at 10, 20, 30 and 40G with a pulse duration of 10 to 12 milliseconds. Each accelerometer was dropped in each of the three orthogonal axes including both directions in the 1-3 axis (See Figure 4). The shocks were monitored by an Endevco Model 2213C accelerometer. The amplified output of the Endevco unit was displayed as a trace on the screen of a Tektronic model 531A oscilloscope and photographed for evaluation. The fluid oscillator timers and recording tapes in the triaxial accelerometers were operating during the shock teats. Following the tests the recorder tapes were photographed under magnification to assist in study and evaluation of the data. Photographs of the tapes together with the input impulses are shown in Figures 15, 16 and 17.

Mounting the triaxial accelerometers on the shock stands presented some problems and may account for some of the apparent malfunctions mentioned below. To facilitate mounting, the cylindrical housing was removed from the accelerometer as shown in Figure 4. The auxiliary high pressure gas supply unit shown in Figure 3 was not shock tested. The fluid oscillator timers were operated by regulated, compressed air supplied from the laboratory system during these tests.

Shock tests in axis 5 were made with the heavy mounting plate of the accelerometer bolted directly to the shock

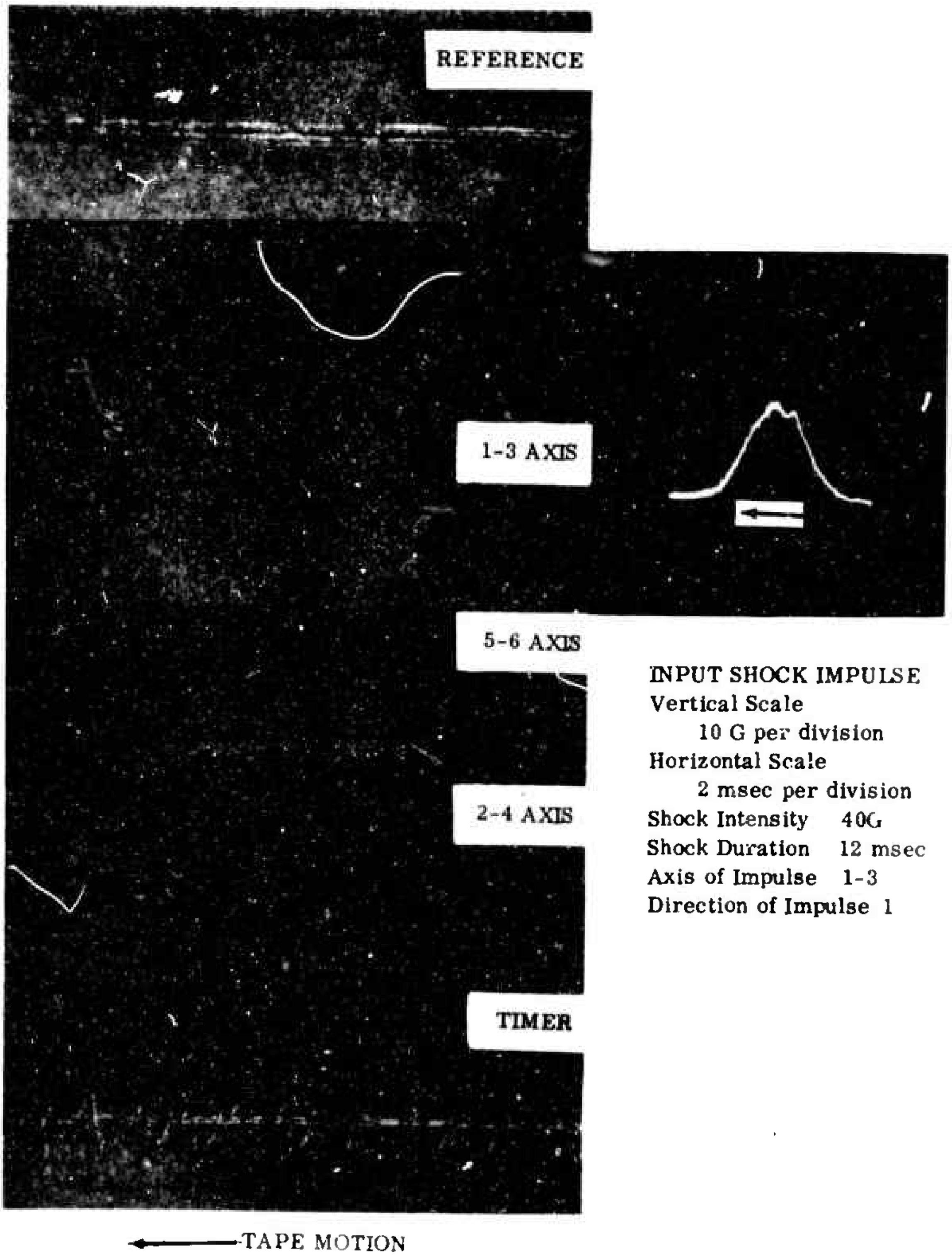




INPUT SHOCK IMPULSE
Vertical Scale
30 G per division
Horizontal Scale
2 msec per division

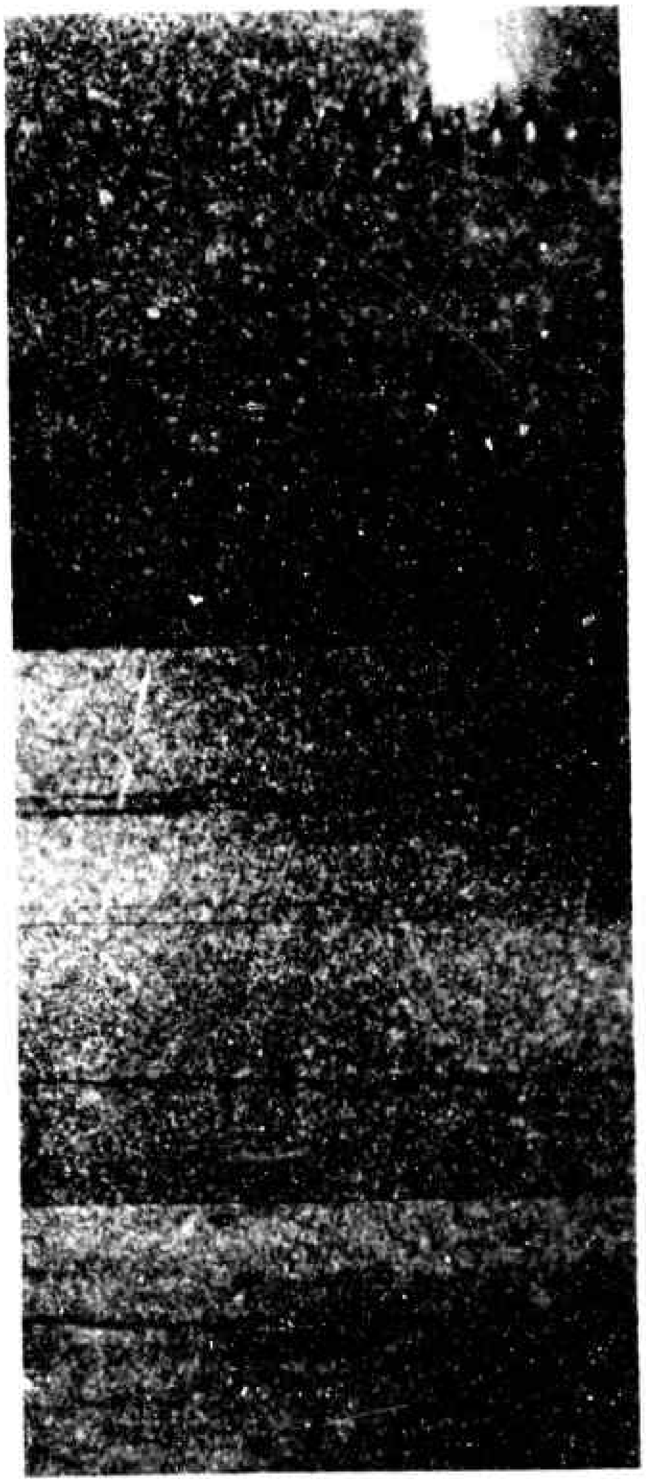
Shock Intensity	150 G
Shock Duration	12 msec
Axis of Impulse	5-6
Direction of Impulse	5

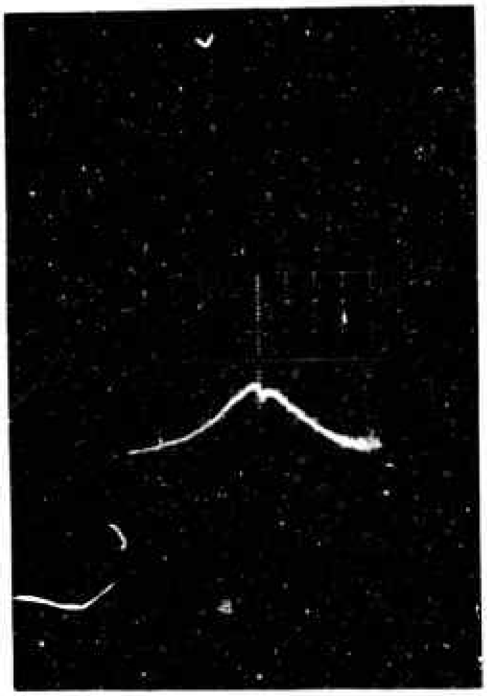
Figure 15 Triaxial Accelerometer Traces, Shock Test.



INPUT SHOCK IMPULSE
Vertical Scale
10 G per division
Horizontal Scale
2 msec per division
Shock Intensity 40G
Shock Duration 12 msec
Axis of Impulse 1-3
Direction of Impulse 1

Figure 16 Triaxial Accelerometer Traces, Shock Test.





INPUT SHOCK IMPULSE
Vertical Scale
30 G per division
Horizontal Scale
2 msec per division

Shock Intensity	60 G
Shock Duration	13 msec
Axis of Impulse	2-4
Direction of Impulse	2

Figure 17 Triaxial Accelerometer Traces, Shock Test.

stand. In axes 1-3 and 2-4 the accelerometer was mounted in the manner shown in Figure 18.

Figure 4 shows two of the four steel straps which fasten the heavy mounting plate of the accelerometer to the seismic mass housing. During the drop tests relative motion was observed between these two heavy components. It seems reasonable to assume that such motion would develop forces which would be sensed by the seismic mass to produce recorded cross-talk. The recorder and associated components were cantilevered at one end of the accelerometer and undoubtedly moved with respect to the seismic mass housing when subjected to shock impulses. This motion would account for some or all of the indicated tape shift. Any relative motion of the component parts of the fluid coupling conduits that would affect the conduit volume would also affect the stylus deflection of the particular axis involved.

Examination of the accelerometer recorder tapes used in the shock tests provided the following information:

First: The response of the triaxial accelerometers to accelerations along a given axis was good. There were 54 separate drops involving three accelerometers in three axes each. Good responses were recorded in 43 drops or about 80% of the total. In the remaining 11 drops (all involving one instrument) the responses were extremely low in amplitude and no attempt was made to measure the deflections.

Second: Undesirable cross-talk was prevalent. Cross-talk in these triaxial accelerometers may be roughly defined as a recorded response in one or both axes at right angles to the direction of the input acceleration. Cross-talk was recorded in both of the axes at right angles to the direction of the drop in almost every one of the 54 drops.

Third: There was evidence of lateral movement of the recorder tape, i.e., motion along the axis of the five stylus points in many of the drops. In about 20% of the drops there was a definite shift in the tape position as indicated by an off-set in the reference trace. In an additional 40% of the drops the tape motion was oscillatory as indicated by a wavy reference trace. Since the reference stylus was fastened to the plate on which the recorder was mounted, relative motion of the recorder with respect to its mounting plate is indicated.

Fourth: Tape reversal as indicated by loops in the traces of one or more stylii occurred in more than 40% of the drops.

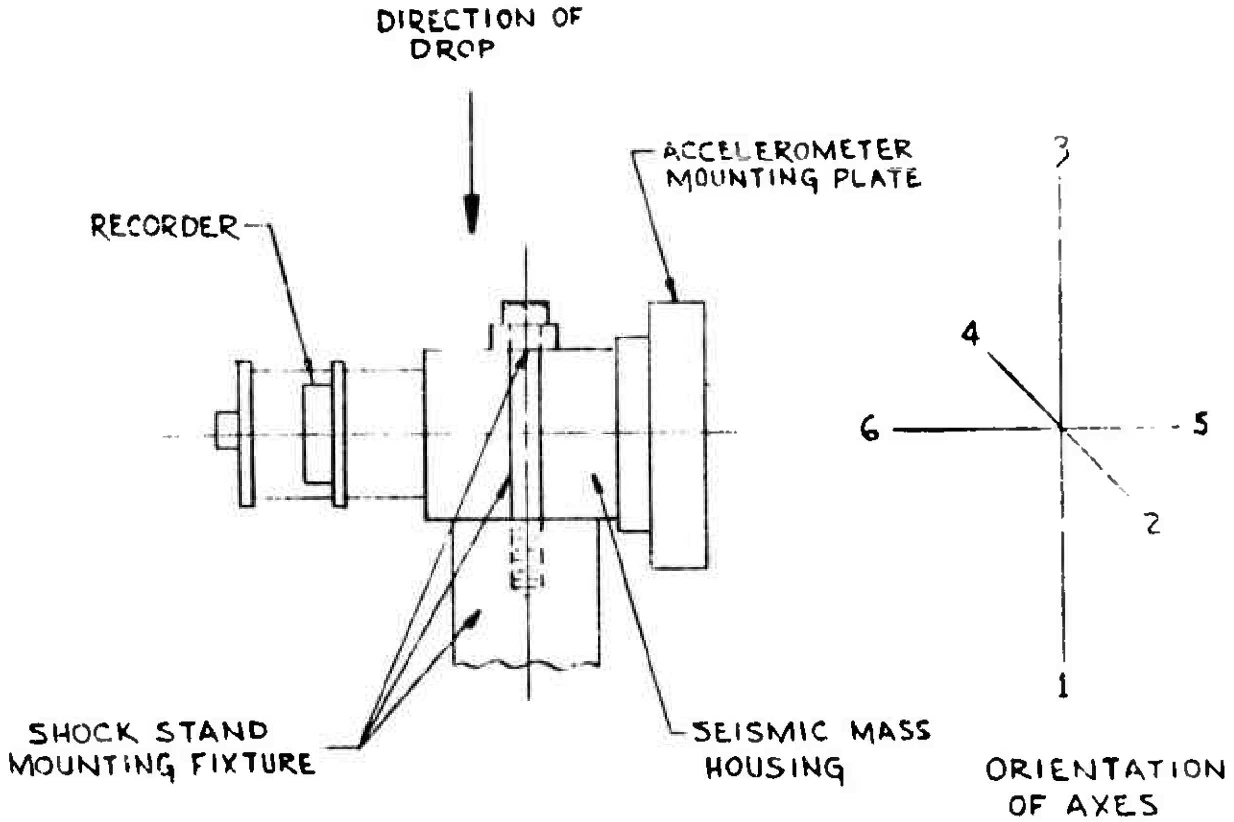


Figure 18 Sketch Showing Accelerometer Mounted on Shock Test Fixture.

Fifth: Good, readable timing traces were produced in about 40% of the drops. However, this may be a function of stylus adjustment. For example, most of the timing traces for the 20G accelerometer were good. About half of the timing traces for one of the 76G accelerometers were good, while all of the traces for the second 76G accelerometer were poor.

Sixth: Discontinuity in one or more of the traces was observed in about 35% of the drops. This malfunction probably was due to lack of balance in the stylii mounting assemblies, or to looseness in the recorder mounting.

Deflections of the accelerometer stylii as recorded on the tapes were measured for each drop where there was a good response. Typical data for one accelerometer are plotted as deflection versus acceleration curves in Figure 19.

A.3.2.3 Calibration

One 76G accelerometer, No. 1X-76G, was recalibrated on the centrifuge in all three axes and in both directions on the 1-3 axis as part of the Post-Snowball test program. The test was identical to that used in the Pre-Snowball calibrations. Pre-Snowball and Post-Snowball calibrations and Post-Snowball shock tests are plotted on stylus deflection versus acceleration charts for the respective axes in Figure 20 for comparison.

It is obvious that there is lack of close agreement among the sets of data. In the #5 axis, the "post" deflections are generally lower than the "pre" data. In #2 and #1-3 axes the reverse holds true. The probable explanation for the difference is simply that the coupling fluid conduits were not completely filled with fluid. For example, in the course of examining and inspecting the accelerometers some coupling fluid escaped and was replaced.

All of the shock induced deflections are higher than the corresponding centrifuge values. Two explanations are suggested.

1. There was amplification of the shock pulse within the accelerometer structure, due to relative motion of components.

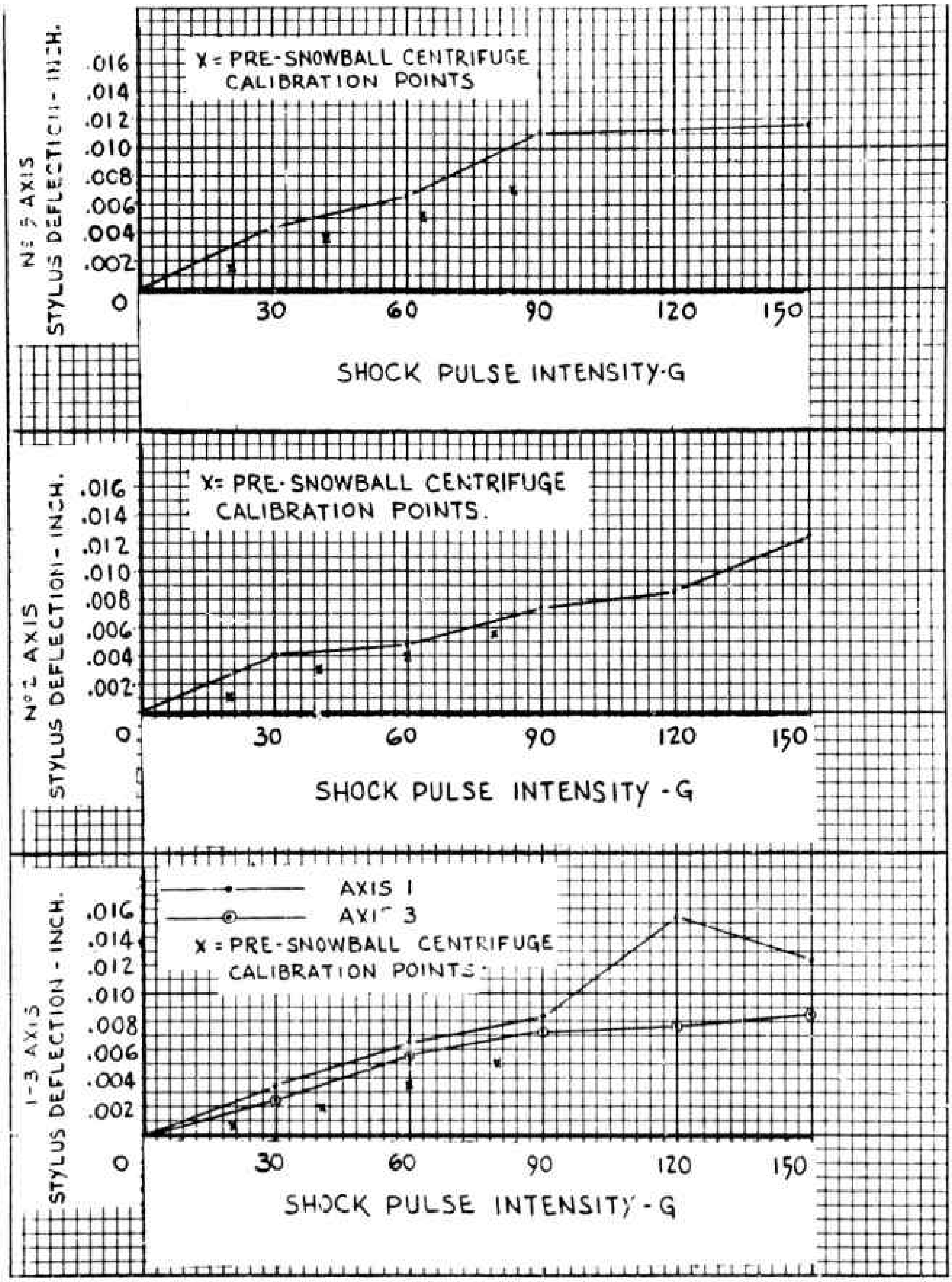


Figure 19 Post-Snowball Shock Tests, Triaxial Accelerometer.

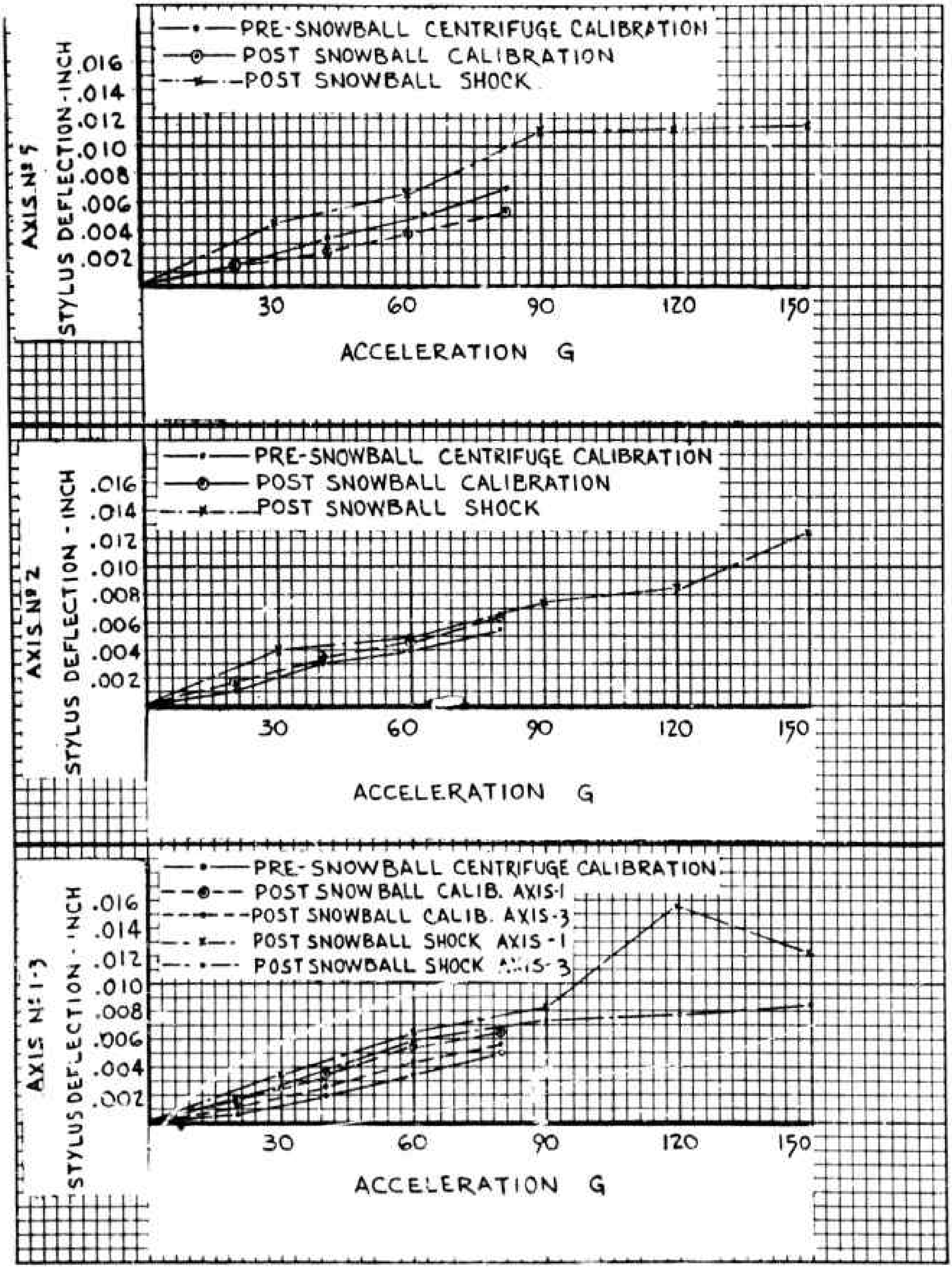


Figure 20 Comparison of Accelerometer Tests.

2. There was a shift in the recorder and its mounting plate with respect to the supports for the sensing stylii.

A.3.2.4 Vibration Test

A Vibration test was performed in an attempt to determine the frequency response characteristics of the triaxial accelerometer. The test results were not satisfactory due to apparent instability of the recorder structure, and no useful data was obtained.

A.4 CONCLUSIONS AND RECOMMENDATIONS

Laboratory tests performed for the Operation Snowball program have provided a great deal of information applicable to the development of prototype, self-contained blast gages and accelerometers for R & D Contract DA-36-034-AMC-0232(X).

The blast pressure gages and accelerometers used in the Snowball tests performed well enough to indicate that with further development and refinement of the basic designs, practical, self-contained recording instruments can be produced for environments above the 200 PSI level. The blast pressure sensor, consisting of a stylus mounted on a diaphragm proved capable of scribing a readable trace on a moving steel tape. The blast pressure sensor calibration is stable. The fluid oscillator will produce a nominal 500 cps timing trace (although somewhat distorted) on a moving steel tape. The triaxial accelerometer design demonstrated an ability to record three channels on a single moving tape.

In general, the structures of the blast pressure gages and accelerometers require additional review and analysis and perhaps redesign to prevent relative motion of the different parts when subjected to shock and vibration. There are obvious deficiencies in the designs which contribute to some of the problems. Specific recommendations follow:

1. Provide increased stylus deflection for the triaxial accelerometer sensors. Snowball accelerometers had deflections of .007" to .009" over the rated acceleration ranges. At leaat double the deflection is desired.

2. Refine the fluid oscillator to (1) improve reliability (i.e. a more rugged design is required), (2) improve wave shape and (3) reduce gas flow requirements.

3. Improve the tape recorder design (1) to prevent shifting of the tape on the recording drum as well as tape reversal. (Consider use of two tapes, one for recording and for motive power), (2) to provide a simpler method of installing the recording tape.

4. Redesign the triaxial accelerometer membrane chambers to prevent bottoming of the membrane diaphragms.

5. In the blast pressure gage, remove reference stylus from recorder frame and attach to blast pressure sensor frame.

6. Strengthen the mounting structure for the recorder in the triaxial accelerometer.

7. Balance the stylus assemblies in the accelerometers.

8. Overcome the cross-talk problem.

9. Develop means for completely filling the fluid cavities in the accelerometer.

10. Reduce the size of the gas supply and regulator package for fluid oscillator operation.

From the conclusions and recommendations listed, it is obvious that many refinements and improvements are necessary to make the blast pressure gages and accelerometers ready for regular field use. It is unfortunate that there was not enough time prior to the field test to have discovered and corrected some or all of the faults in the instruments, which showed up in the field test and in the Post-Snowball tests. The test results show that the principal improvement needed in the self-recording instruments is the capability to produce good, readable traces under the environmental conditions associated with blast pressure levels above 200 PSI. The information and experience gained from the Snowball program will be of great help in the development of better, more reliable instruments for the higher pressure levels.

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13 ABSTRACT

This report presents a description and evaluation of experimental self-recording pressure-time gages and triaxial accelerometers tested during Operation Snowball, an air blast experiment conducted at Suffield Experimental Station, Alberta, Canada. Values of shock overpressure, duration of positive phase of the shock wave, and impulse derived from the records of these gages are compared to graphs of similar parameters plotted from measurements obtained by Project 1.1 which was responsible for making primary measurements of the air blast parameters.

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Sensor						
Prototype						
Arrival Time						
Overpressure						

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